THE DIFFERENTIATION AND CONTACT METAMORPHISM OF THE SNOWBANK LAKE SYENITE IN THE VERMILION IRON-BEARING REGION OF MINNESOTA

BY

CLARENCE SAMUEL ROSS

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W. S. Bayley
In Charge of Thesis

T. T. Quirke
Head of Department

Recommendation concurred in*

T. T. Quirke
W. S. Bayley
D. F. McFarland
E. G. Washburn
Morris M. Leighton

Committee on Final Examination*

*Required for doctor's degree but not for master's

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I. INTRODUCTION.

Location

The Snowbank Lake region lies in the eastern part of the Vermilion Iron-Bearing District of Minnesota, being situated on the meridian 95°25' west from Greenwich and at 48° north latitude. It is about 90 miles north and east from Duluth, 3 miles south of the Canadian boundary, and 85 miles due east from Grand Portage on Lake Superior. Snowbank Lake is most easily reached from Ely or Winton, Minnesota, on the Duluth and Iron Range Railway; and involves a canoe trip of approximately 36 miles by way of Fall, Basewood, Sucker, Newfound, Ensign and Crooked Lakes. Portages are difficult in the stage of the journey between Ensign and Snowbank lakes.

Description

Snowbank Lake is an irregular body of water about five and a half miles in its greatest diameter, lying in a basin which is nearly co-extensive with the distribution of the Snowbank Lake syenite which is the principal subject of this study. Its irregular shape is similar to that of nearly all lakes of this region lying in areas of granite rocks. The lake lies at an elevation of about 1420 feet above sea level. The maximum elevation of the region is 1800 feet, which is attained at Disappointment Mountain. This gives a maximum relief of 380 feet, but the average relief is not over 200 feet.

The syenite area in the immediate neighborhood of the lake is surrounded by an area of conglomerates, slates and greenstones. In this region the hills are bold, rounded knobs, but in the syenite area there is less relief and much of the country is occupied by lake and swamp. In the region of the Duluth gabbro, which lies just to the south of Snowbank and Round lakes, the land rises as a plateau of low relief about 200 feet above the surface of the lakes. (See Plate VI. A-B)

Snowbank Lake contains numerous islands, varying in size from mere points up to a maximum diameter of one mile. Round Lake is a nearly circular body of water lying about one-half mile southeast of Snowbank Lake.

Drainage

The drainage is northward by way of Crooked, Ensign, Newfound, Sucker and Basswood lakes to Rainy Lake; then by way of Rainy Lake to Lake of the Woods, and Lake Winnipeg, finally entering Hudson Bay through Nelson River. The "boundary route" of travel lies through Birch Lake, three miles to the north. The lakes and streams afford the only means of access to the region.

The region has been very heavily glaciated, leaving very little soil upon the rocks. Where the original forest still stands, the rocks are covered by a thick growth of moss, but most of the region has been subjected to forest fires and the moss has been burned away. For these reasons, rock exposures are numerous and good, but travel is exceedingly difficult.

Stratigraphy

With the exception of the glacial drift, all the rocks exposed in the Vermilion district are pre-Cambrian. The stratigraphic sec-

tion is as follows:

Quaternary System:	
Pleistocene:	Drift
Algonkian System:	
Keweenawan Series:	(Duluth gabbro (Logan sills
Huronian Series:	
Upper Huronian (Animikie):	(Rove slate (Gunflint formation
Middle and Lower Huronian:	(Intrusive rocks (Granites (Snowbank Lake syenite, (Cacaquabic granite, Giants (Range granite, porphyries and (lamprophyres) ((Sedimentary rocks (Knife Lake slate (Agawa iron formation (Ogishke conglomerate
Archean System:	
Laurentian Series:	(Intrusives (Granite of Basswood and Saganaga (Lakes
Keewatin Series:	(Soudan formation (Ely greenstone

Previous geologic work

Snowbank Lake lies only a few miles off "the boundary" route which has been a main thoroughfare of travel for ages, for long before the white fur traders began to seek the riches that lay to the northwest, the Indians had used the same routes of travel on their hunting and fishing expeditions. Prairie Portage between Sucker and Basswood lakes has been a famous camping place for whites and Indians for hundreds of years. Notwithstanding its proximity to routes of travel, the Snowbank Lake district has been but little studied, and this in spite of its forming a part of the Vermilion Iron-Bearing Region.

Jean N. Nicollet added much to the knowledge of the region by his journey of discovery in 1634. Some of those doing important early work on the general region were: Douglass Houghton[1] in 1841;

1. Houghton, Douglass, 4th Ann. Report of the State Geologist, State of Mich., House of Rep. Doc. 27, 1841.

and David Dale Owen[2] in 1852.

2. Owen, David Dale,"Rep. of a Geol. Survey of Wis., Iowa and Minn." Phila. 1852.

No work on the Snowbank region itself appears to have been accomplished until the establishment of the Minnesota Geological and Natural History Survey in 1872. In the 13th Annual Report for 1884 N. H. Winchell[3] discusses the stratigraphy of the region, dividing

3. Winchell, N. H., 13th Ann. Report Minn. Geol. and Nat. Hist. Surv., 1884, p. 128, St. Paul 1885.

the rocks into five groups. He makes the following remarks in regard to the second group which lies just below the gabbro, and which would correspond to the Huronian: "Below this granite and gabbro group is a series of strata that may be designated by the general term of mica schist group......... This division is penetrated by veins and masses of red biotite granite, which appear to be intrusive in somewhat the same manner as the red granite in the gabbro overlying. However, whether this granite is exotic, or can be referred to aqueo-igneous fusion and transmission of the sedimentaries in a plastic state through fissures in the adjacent formations, is a question which is still a matter of earnest investigation. The existence of the great associated gabbro is suggestive, if not demonstrative, of the presence of an adequate agent for such metamorphism, unless it be claimed, indeed, that such an extravasion of molten rocks could take place without any marked and traceable ef-

fect on the contiguous formations. These granite veins penetrate only through the overlying gabbro and this underlying schist. They are wanting or comparatively rare throughout the rest of the crystalline rocks. On the other hand, there is an abundance of diabase and other doloritic rocks, in the form of dykes, throughout all the crystalline strata. This points to the more local nature of the origination of these granitic veins, and hence to the metamorphic nature of the granite mass with which they are connected."

In the year 1886 Alexander Winchell[1] visited the region and

1. Winchell, A., 15th Ann. Report Minn. Geol. and Nat. Hist. Surv., p. 124, St. Paul 1887.

described specimens, making the following statements regarding the region: "Snowbank Lake is about 5 miles long and the main body of it is two and a quarter miles broad. The southern half of its outline is deeply indented by many irregular capes and peninsulas, and the surface of that part is much broken by islands, one of which is a mile in length.......... Snowbank Lake is apparently but little frequented. Trails to and from it are very obscure and difficult. Much of the lake is shallow, and dangerous shoals and reefs are frequent. Many rock fragments also rise abruptly to and near the surface, in places where the water is generally deep. The dangers of canoeing are apt to be much increased by the prevalence of high winds which sweep over the broad expanse of surface.........

"The lake is bound in a massive rim of crystalline rocks. These are prevailingly syenite, but near the eastern extremity they become gray wackenitic, hard, badly bedded and decidedly basic in external aspect."

In the same volume, (p. 177) the same geologist makes a corre-

lation of the granite on White Iron Lake, now believed to be a part of the Giants Range granite, with the Snowbank Lake granite in the following words: "The southern mass of gneissic crystallines envi-rons the whole of White Iron Lake, and the greater part of Garden Lake, and appears on Kawishiwi in T. 63-9. What appears to be the same reappears on Snowbank Lake--an unplatted, unvisited township intervening (T. 63-10). The formation completely surrounds Snow-bank Lake."

In 1888 H. V. Winchell[1] discusses the syenite on Round Lake as

1. Winchell, H. V., 17th Ann. Report Minn. Geol. and Nat. Hist. Surv., p. 119, St. Paul 1889.

follows: "The west side of Round Lake has syenite around its shores. This becomes dark and siliceous and changed into a peculiar rock that seems to have been affected by the proximity of some igneous rock or other metamorphic agent." This reference does not seem quite clear but it may be that Winchell observed the metamorphism of the syenite by the gabbro.

In 1891 U. S. Grant[2] published the results of a short visit to

2. Grant, U. S., 20th Ann. Report Minn. Geol. and Nat. Hist. Surv., pp. 59-69, Minneapolis, 1891.

the Snowbank Lake region. Numerous specimens were described, but he did not publish his conclusions until later. (See p. 9.)

In 1893 A. H. Elftman[3] made a brief study of the Snowbank Lake

3. Elftman, A. H., 22nd Ann. Report Minn. Geol. and Nat. Hist. Surv., pp. 151-159, Minneapolis, 1894.

granite and comes to the following conclusions: "The granite of Snow-bank Lake presents an interesting problem; as there is some evidence to show that there are two distinct granites, an augite and a horn-blende granite. The most reasonable explanation that can be as-

signed to the occurrence of these granites in the same area is that they are parts of the same magma and that the hornblendic variety was erupted at a later date and perhaps at a time of greater violence than that of the eruption of the augite granite, which formed the outer portion of the magma......... There is sufficient reason to place all the eruptive pre-Animikie granite of Minnesota into one period......... On thin section these granites are found to consist of fresh augite or hornblende with all degrees of alteration of the former to the latter, showing conclusively the secondary origin of the hornblende."

In 1897 N. H. Winchell[1] made a third visit to the Snowbank Lake

1. Winchell, N. H., 24th Ann. Report Minn. Geol. and Nat. Hist.Surv. pp. 59-66, Minneapolis 1899.

region to check up some of the conclusions of Elftman, who had correlated the porphyries on the Kawishiwi River with those on Snowbank Lake, and thought he had found evidence of two conglomerates, one older and one younger than the granite, with dikes of granite in the lower and pebbles of the same granite in the upper. Winchell found evidence that there was but one conglomerate. It was found that red granite dikes cut across augite granite and it is suggested that the augite granite may be the older, but of this there is no proof. Winchell also asserted that he found new proof that the porphyry was derived from the sediments by metamorphism.

In the discussion of the geology of Lake County, N. H. Winchell[2]

2. Winchell, N. H., Final Report Minn. Geol. and Nat. Hist. Surv., Vol. IV., pp. 287-8, St. Paul 1899.

says of the Snowbank granite: "The lake itself occupies the most of the area of this granite, but about the shores it is frequently seen

penetrating the conglomerate and the mica schists of the Upper Keewatin. It extends nearly across the narrow strip of land separating Snowbank from Disappointment Lake. It has been noted in places that this granite is augitic, resembling in that respect that of the region of Kekequabic Lake. It is not believed that this is due to any difference of origin or of date, but that the augitic character appears sporadically according to the nature of the clastics from the metamorphism and fusion of which the granite is supposed to have been derived..........

"There is a noticeable parallel between the geology of this lake and that of Kekequabic Lake. In each there is a porphyritic conglomerate, a porphyry which becomes granite, and a granite which is sometimes augitic. At Kekequabic Lake the porphyry is known to be sometimes augitic, but that character has not yet been observed certainly in the porphyry of Snowbank Lake. Field observations by nearly all members of the survey testify that the conglomerate is so nearly related to the porphyry that they can not be separated in many instances.......... The 'porphyritic' appearance is due therefore to the nature of the debris, and not to a formation of feldspars afterwards. These feldspars are not always found, but the rock grades into graywacke and to argillite. By the metamorphism which was imposed on this fragmental rock, and which was accompanied by pressure and folding, and resulted in the granitic area, in the complete fusion of the clastic materials, a great variety of structural as well as of petrographic facts of importance and high geologic interest were developed."

In the same volume U. S. Grant[1] has a report on "The geology of

the Snowbank Lake Plate." The following are Grant's more important

1. Grant, U. S., Ibid, pp. 420-433.

conclusions.

"Quartz porphyry:--In this district, especially west and southwest of Snowbank Lake, in T. 63-9, are considerable areas of porphyritic rocks. These vary considerably, but in general are light colored, gray to reddish, fine-grained rocks with porphyritic crystals of feldspar and also frequently of quartz......... As a whole the porphyry seems not to have been subjected to great dynamic forces, and is still massive, breaking down into sharply angular blocks. The age of the porphyry is not known; in fact, there may be porphyry of more than one date, but it is thought to be in general later than the Lower Keewatin greenstones, and earlier than the Upper Keewatin conglomerates, for it is found cutting the former and included as pebbles in the latter."

"Granite:--At Snowbank and Disappointment lakes, especially at the former, much granite is seen. This lake lies in an area of this rock, which appears on the islands and on many places on the shores. There is evidence that there are here two masses of granite of different date, but the separation can not be made with certainty, although it seems that one granite, a red or hornblende granite, is later than and cuts the other, a gray or augite granite. That part of the granite at Snowbank Lake is intrusive in the Keewating clastics is evident......... On the northwest shores of Disappointment Lake is a conglomerate, which holds red granite pebbles very similar to dikes of granite, cutting this conglomerate. This necessitates the presence of a granite in this vicinity earlier

than the conglomerate. Whether this conglomerate is exposed nearby is not known."

Grant says of the relation between the Snowbank and Kawishiwi granites, "The gabbro soon passes over this area of granite (Kawishiwi) on to the Keewatin rocks thus completely shutting off the surface exposure of the granite, which rock is perhaps continuous beneath the gabbro with the granite of Snowbank Lake."

In 1903 the U. S. Geological Survey monograph on the Vermilion Iron-Bearing Region was published. The following quotations will

Clements, J. Morgan, U. S. Geol. Surv. Mono. 45, pp. 120, 341, 361-364, Washington, 1903.

show the extent of the work on the Snowbank region: "The granite occurs in good exposures in the vicinity predominantly pink to red in color, although on fresh fracture it is a gray to flesh colored rock. Some facies, however, are much darker colored, as a result of a higher content of dark minerals than is contained in the normal granite. The granite varies from the fine-grained to the coarse-grained form, the medium-grained facies being the most abundant. The porphyries are developed as granite-porphyries and micropegmatite-porphyries with feldspar, augite, and quartz phenocrysts in a fine-grained groundmass. These porphyries as well as the fine-grained granites occur chiefly as offshoots from the medium-grained mass, and penetrate the sediments which surround the granite massive.........."

"Mineralogically the Snowbank granite varies from a normal mica and hornblende granite, and, by loss of quartz, to a syenite. The hornblende granites are invariably much darker than the mica granites. These last tend to reddish colors, while the hornblende

granites are usually dark gray or red if the orthoclase is very prominent and considerably weathered. As the green augite takes the place of hornblende, these hornblende granites pass over into augite-granite. The augite-granite is grayish, flesh-colored to red, medium-grained granite, and does not differ materially from the normal Snowbank mica-and hornblende-granite in microscopic appearance. The red augite-granite has been observed to cut the Snowbank granite. This red augite-granite is also reported to be cut by the hornblende-granite. Both observations are correct, the explanation, as it appears to me, being that they are of essentially the same age, and are differentiation products of the same magma........."

The sediments near the granite have been very much changed. They are full of mica in relatively large crystals, and in general the rocks have been recrystallized until they are now in places mica-schists. The crystalline character of these rocks is most noticeable near their contact with the main granite mass, and at places where they are cut through by numerous dikes of the granite, and where the fragments of the sediments are enclosed in the dike rocks. The farther away from this contact we go the less numerous the dikes become and the less pronounced are the indications of metamorphism until, at a distance varying in places from a half-mile to a mile, the sediments seem to show their normal character. The presence of the dikes in the sediments and the contact effect of the granite on the sediments clearly show the intrusive character of the granite...

"The granite has not been found in actual contact with the large mass of the Duluth gabbro lying south of and next to it. Along the contact there is a slight topographic break, occupied by

low ground, in which exposures are wanting. The granite is of Lower Huronian age, and there can be no doubt that the Duluth gabbro is younger than it is. However, if the gabbro exercised any metamorphic effects on the granite they have not been observed, nor have any dikes that could be traced to the gabbro been found cutting through it."

Van Hise and Leith in 1911 mention the intrusion and metamorphism of the slates by the granite and give a brief description of the igneous rock.

Van Hise and Leith, "On the Geology of the Lake Superior Region," U. S. Geol. Surv. Mono. 52, pp. 135-136, Washington, 1911.

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II. THE SNOWBANK SYENITE.

In the review of previous work it has been seen that most of the early writers called the intrusive mass of the Snowbank Lake region a syenite, but the later ones adopted the term granite. It will be shown in this paper that only one small area is characterized by notable proportions of quartz, and that elsewhere quartz is confined to the border phases as a very minor constituent. For these reasons the more correct term syenite will be applied to this interesting intrusive mass.

Distribution

The basin of Snowbank Lake lies almost entirely within the syenite area. Syenite forms two projecting points along the north shore of the lake; all the islands that are especially numerous in the south half of the lake; a narrow border along the east shore; and about four square miles south of the main body of the lake, and west of it a southern arm, and the area between this arm and Round Lake to the east.

The rock in the central part of the area on Boot Island and the adjacent headland to the southwest is the most femic in character, being characterized by relatively large amounts of biotite, of hornblende, or of both. In the area between Snowbank, Round and Disappointment lakes there occurs a small area of very quartzose granite. The most uniform phase of the intrusive is a microcline, oligoclase-syenite, which has been considered the normal facies. This occurs on most of the islands in the south and west portions of the lake, and on the adjacent mainland. The southeast portion of the area is characterized by an extremely variable, sodic syenite. Along the

western part of the lake the headlands are composed of gray quartz porphyry.

The syenite is intrusive into Knife Lake Slate on the north, and into Ogishki Conglomerate on the east and west (See Plate VII. A-B), formations which are of Lower Huronian age, the Knife Lake Slate being conformably above the Ogishki Conglomerate.

Just to the south of Snowbank and Round lakes lies the Duluth gabbro which has overridden and concealed an unknown portion of the syenite. Dikes and dike differentiates of the syenite are common within the main body of the syenite and in the conglomerates, being especially numerous in the area between Snowbank, Round and Disappointment lakes.

Mineral Composition

The minerals of any igneous rock are conveniently divided into those that are original; that is, those formed directly from the crystallizing magma; and those that are secondary, being derived from earlier minerals by subsequent alteration. The original minerals include those that are essential to any particular rock type and those that are accessory.

The essential minerals that appear to be original in all cases are diopside, aegerite-augite, and quartz. Hornblende is secondary in most cases, but some of it is undoubtedly primary in origin. Biotite is usually primary but a small portion is the result of the alteration of pyroxene. Most of the feldspars are original but some are secondary.

The accessory minerals that are original are apatite, titanite, a very small amount of zircon, rutile inclusions in biotite, and

that portion of the magnetite which is idiomorphic in outline.

The secondary minerals are colorless mica, calcite, epidote, limonite, hematite, chlorite, fibrolite. Some of the feldspars are secondary as is part of the biotite, most of the hornblende, and that part of the magnetite resulting from the alteration of hornblende.

ORDER OF CRYSTALLIZATION. The first mineral to crystallize was apatite, which is very abundant, usually occurring in idiomorphic prisms. Magnetite is very common and is earlier than the titanite which frequently forms a narrow border entirely surrounding the iron oxide. This was followed by diopside, that which formed last showing a progressive increase in the proportion of the acmite molecule. Biotite formed next, then aegerite-augite, and lastly hornblendes among the femic minerals. Of the feldspars, oligoclase and microcline were the first to form, followed by albite and orthoclase. Where quartz is present it was the last mineral to crystallize.

Primary Components

FELDSPARS. The various phases of the Snowbank syenite contain feldspars distinguished by rather striking peculiarities, the common possession of which indicates common origin. The striated feldspars are sodic members of the albite-anorthite series and microcline. The non-striated feldspars are oligoclase-albite occurring as distinct phenocrysts and complex intergrowths with potassic feldspars, and orthoclase.

Named in the order of their relative abundance the feldspars are non-striated soda plagioclase, microcline, striated plagioclase and orthoclase.

In spite of a certain amount of overlapping there is the following rather definite sequence in the order of crystallization of the various feldspars: andesine, oligoclase, microcline, non-striated albite, orthoclase. Part of the microcline and oligoclase is derived from earlier feldspars through changes subsequent to the crystallization and these will be discussed as a group to themselves.

Striated Plagioclase. The striated feldspars, varying in composition from andesine to albite, are only secondary in importance to the non-striated feldspars discussed later. Striated plagioclase, however, forms fully 60 per cent of the rock on Boot Island. It is important, though not predominant in a very large proportion of the syenite and is entirely absent from the rock in only one small area.

The plagioclases in the femic differentiates of the syenite on Boot Island have an angle of extinction ranging from $+9^{\circ}$ to -5°, indicating that the most calcic feldspar of this region is andesine and the more sodic one striated oligoclase.

The plagioclase of the predominant type of the syenite has an extinction of about $-7^{\circ}30'$ indicating an oligoclase-albite of about the composition $Ab_{85}An_{15}$. Zoning is very common, with the outer zone the most alkalic. The increase in the concentration of the albite molecule in the crystallizing feldspar was gradual in most cases, but in a few crystals the change was so sudden that there appears to be a sharp contact between the two kinds of plagioclase. In many crystals the interior portion is distinctly striated oligoclase-albite and the exterior is non-striated albite.

Non-striated Oligoclase-albite. The proportion of non-striated plagioclase in the Snowbank syenite varies from 25 to nearly 100 per cent of the entire rock mass. It is least abundant in the more

femic phases of the rock on Boot Island and most abundant along the south part of the syenite area. The non-striated feldspar occurs both as phenocrysts and ground-mass grains. It is usually associated with striated feldspar, and often forms an outer zone around twinned grains. Zoning occurs in most of the grains, their outer part being richest in albite; but the progressive concentration of that molecule was far from uniform. Some grains possess very albitic outer zones showing sharp contacts with the interior portion composed of more calcic feldspar. The non-striated plagioclases are idiomorphic to hypidiomorphic, but always idiomorphic in relation to any quartz that may be present.

A detailed study of small grains of this feldspar shows that the optical character is always positive (+), and the acute bisectrix is perpendicular to the (OIO) face. The extinction angles on the (OOI) face are 3° to 4°, and on the (OIO) face are 11° to 15°. This indicates a plagioclase of the composition $Ab_{85}An_{15}$ to $Ab_{93}An_{7}$. The position of the acute bisectrix indicates a plagioclase somewhat

H. Rosenbusch and E. A. Wülfing, "Mikroskopische Physiographie." I., 2, p. 345. Suttgart, 1905.

richer in albite than $Ab_{90}An_{10}$. Thus the last feldspar to form was very nearly pure albite.

Johannsen, Albert, "Determination of Rock Forming Minerals." p.78 N. Y. 1908.

Twinning after the albite law does not occur, but twinning after the Carlsbad law is common in most of the crystals of albite in the parts of the syenite along the southern border of the area.

Microchemical tests on selected grains of this feldspar indicate that part of the soda is replaced by potassium, a fact which may ex-

plain the absence of striations.

Much of the albite occurs as complex intergrowths with microcline. Their occurrence will be discussed in the section on intergrowths.

The albite shows little alteration in most cases, and is very glassy in appearance.

Microcline. Microcline is the most characteristic though not always the predominate feldspar of the main central mass of the syenite. Its grains are usually hypidiomorphic, but are idiomorphic in their relation to the quartz when that mineral is present. The size of the microcline grains varies greatly, and some of them are distinct phenocrysts. The relation of the microcline to the grains with which it is in contact, and especially to quartz, indicates that it is usually original. In some specimens, however, the mineral is recrystallized, in which case the grains are very fresh in appearance and occur on the contacts between original grains or entirely within them. Usually the original microcline shows but little alteration, and the secondary microcline shows none.

Zoning is present in some of the microcline phenocrysts, with the angle of extinction becoming larger on the margin of the grain. The twinning structure is very fine in the interior of some microcline grains, becoming coarser on the outer border. Iddings says,

Iddings, Jos. P., "Rock Minerals," p. 235. New York 1911.

"In potash-soda-feldspars rich in soda there is extremely minute to almost submicroscopic multiple twinning as in microcline......... In fact the presence of extremely minute microcline twinning is an indication of abundant soda in potash-feldspar." Thus it seems

probable that during the growth of microcline grains the soda microcline molecule formed a gradually decreasing isomorphous mixture with the microcline molecule.

The microscope shows the microcline to be so intergrown with plagioclase that nothing can be deduced as to the composition of the microcline from ordinary rock analysis, but microchemical tests on carefully isolated grains indicate the presence of important amounts of soda. This fact and the absence of grating structure indicate that at least part of the microcline is soda microcline.

Microcline occurs in complex intergrowths with sodic feldspars, and there is evidence that these intergrowths were developed subsequent to the original crystallization. The feldspars of this type will be discussed under the head of intergrowths.

Orthoclase. Orthoclase is the least abundant of all the feldspars, and is entirely absent from some of the femic phases, microcline being the only potassic feldspar in the central portion of the syenite. Its proportion is small in the sodic border phases of the rock and no specimen has been observed containing more than 10 per cent of orthoclase. It is nearly always fresh in appearance, and in many sections it is difficult to distinguish orthoclase from non-striated albite.

Feldspar Intergrowths. Much of the feldspar of the Snowbank syenite occurs as complex intergrowths. The large phenocrysts of the porphyritic syenite on Boot Island are composed of irregular patches of microcline surrounded by lens-like intergrowths of microcline and albite. The grating structure is continuous from areas composed entirely of microcline across areas of intergrown albite

and microcline. (Pl. I.-A and B; Pl. II.-A)

Along the southern border of the syenite area the pattern of the intergrown structure is so fine that the grating structure indicative of microcline is obscured if present, but the relationships are the same as in the phenocrysts just mentioned and the potassic feldspar is undoubtedly microcline, probably soda microcline.

The lens-like inclusions of one feldspar within another are most common in the highly sodic non-striated feldspars, but a few scattered lenses occur in the more basic striated feldspar from Boot Island and they increase in number on the sodic borders of the zoned crystals.

The intergrown feldspars were more satisfactorily studied by means of small grains imbedded in balsam than in thin sections. The optical effect of the feldspar aggregate is that of albite. The smaller lenses have a diameter of less than 0.001 mm., but reach several times that size in some specimens. Their length is about 0.01 to 0.015 mm. and the longest cross-section has a shape similar to the longitudinal section through a cigar, but they are probably slightly flattened in the plane (001). The lenses are developed with a striking parallelism, and the intergrowth takes place along a plane that makes an angle of 73° to 74° with the cleavage parallel to the plane (010), and is approximately parallel to the cleavage in the plane (001). These angles indicate that the intergrowth of the two feldspars is along the plane (501).

The crystallographic continuity of striated plagioclase with non-striated plagioclase, and the progressively increasing proportion of lens-like inclusions toward the border tends to show that

the original feldspar was soda-potassic plagioclase.

Mr. L. E. Kennedy in a report[1] on the Cacaquabic granite has

1. Kennedy, L. E., Unpublished thesis, University of Illinois, 1918.

made a thorough study of similar intergrowths of soda and potassic feldspars in this rock. He shows that they consist of albite and soda microcline, occurring in the form of wavy lenticles. In that rock they do not possess the sharp cigar shaped outline characteristic of the intergrowths in the Snowbank Lake rock, but while the shape differs slightly all other characters are similar.

An explanation of the feldspar intergrowths may be that the feldspar originally crystallizing from the magma was an isomorphous mixture of potassic, sodic and calcic feldspar molecules. Under later conditions, probably during cooling, these mixtures became unstable and two feldspars, one microcline and the other albite, separated from the solid solution of the original crystal. Thus the intergrowths are not due to later metamorphism, but are the result of conditions under which two molecules cease to be mutually soluble in their solid state.

Pentti Eskola says of the microcline Pernio granite of the Ori-

Eskola, Pentti, Bull. "On the Petrology on the Orijarvi Region in Southwestern Finland," Comm. Geol. de Finlande, p. 25, Heslingfors 1914.

jarvi region, "The circumstance that the microcline, originally consolidated as an isomorphous mixture saturated with soda feldspar, had thrown out albite in the form of perthitic laths or zones surrounding those plagioclases adjacent to the microcline, is a phenomenon which is associated with the slow cooling of the mineral, and is no evidence of regional metamorphism." An examination of sections made

from specimens kindly presented to the University of Illinois by Eskola shows that the intergrowths mentioned by him lack the remarkable parallelism of the Snowbank Lake occurrences, but are otherwise similar to these.

Other lines of investigation have suggested that two molecules may form a homogeneous crystal under conditions that induce mutual solubility in the original solid state, and that the molecules of this solid solution may later become insoluble under changed conditions, resulting in the production in two solid phases.

Anderson has studied dark brown needles and plates which are arranged in lines parallel to the different crystallographic planes in certain feldspars. He concludes that they are hematite lamella which have been formed by the unmixing of an originally homogeneous solid solution of the feldspar and hematite (or ferric compound) in such a manner that thin hematite lamellae have separated along structural planes (translation planes) of the feldspar.

Anderson, Olaf, "On Adventurine Feldspars," Amer. Jour. Sci., Ser. 4, Vol. 40, pp. 351-399, 1915.

Such a separation into two phases in the solid state would be exactly similar to that which is known to take place in steel, where a solid solution is formed on crystallization,[1] but on further cooling cementite (iron carbide, Fe_3C) and ferrite (pure iron) separate,

Sauver and Boylston, "Metallography and Heat Treatment of Iron and Steel," Second Edition, pp. 118-142, Cambridge 1916.

giving rise to the eutectoid structure of parallel plates.

F. N. Gould has suggested the "inmixing of a solid solution, or

Gould, F. N., "A Microscopic Study of the Silver Ores and their Associated Minerals," Econ. Geol. Vol. XII., pp. 297-353, 1917.

breakdown of an isomorphous mixture" to explain eutectic-like structures in sulphides.

Micrographic intergrowths of albite and quartz, and of orthoclase and quartz occur in a few specimens of the syenite, but are much more common in the dike rocks to be described later. (See p.63)

Inclusions. Much of the feldspar, and especially the albite, contains long slender needles of fibrolite. These are usually arranged with a common parallelism, and the needles are frequently broken and the two ends slightly separated. Less commonly they are curved or bent upon themselves.

Alteration. Much of the plagioclase feldspar shows alteration to colorless mica. Alteration may extend throughout the grain but more commonly is confined to its calcic central area. Often these central areas containing mica possess an excellent idiomorphic outline even when the grain itself has an irregular outline. Many of the mica plates are in the form of laths with remarkably clear cut outlines, surrounded by nearly fresh feldspar. In a few specimens the feldspar contains a little calcite among the decomposition products, but no kaolin has been observed. Iron oxides occur, but are neither common nor present in large amounts.

PYROXENES. Diopside. Diopside is the most characteristic mafic mineral of the Snowbank syenite. In a few cases it is almost colorless, but usually it possesses a decided green tint, with a very noticeable pleochroism, and there is a strong tendency for the green color to be deeper on the outer border of the crystal. The maximum angle of extinction measured from the (010) cleavage varies from 39° in the nearly colorless grains, up to 50° in those of the darker

green color. In the zoned grains it varies from 39° in the pale center, to a maximum of 47° in the green margin. The optical character is positive (+) Y∥b, Z∧C: = -39° to -50°; and the pleochroism X = applegreen, Y = pale green, Z = colorless; X>Y>Z. The high angle of extinction, the green color and the pleochroism of the outer margin of the grains indicate that the diopside contains a progressively increasing proportion of the acmite molecule, and that only the pale variety with an angle of extinction near 39° is approximately true diopside. Thus the evidence given by the pyroxenes agrees with that presented by the feldspars that during the crystallization of the magma there was an increasing concentration of sodium.

Aegerite-Augite. Deep green aegerite-augite occurs in many specimens of the rock, but it is most beautifully developed in its sodic phases along the southeastern border of the area. It most often occurs as entirely distinct crystals, but occasionally forms masses around diopside, but no zonal relation to the latter has been observed. The color varies from clear yellow to yellow green, to clear emerald green. X = emerald green to dark green, Y = olive green, Z = yellow to yellow brown. X>Y>Z. Y∥b, and Z∧c = -78°. The optical character is positive (+). The relationship of the aegerite-augite to the diopside shows that it represents a later stage in the crystallization of the magma, and one where the concentration of the sodium had progressed further than was the case when the later acmite-bearing diopside formed. The fact that the aegerite-augite does not occur as a zone around diopside is evidence that its crystallization occurred in a later stage and in one distinct

from that of diopside.

Much of the aegerite-augite is very similar in appearance to the hornblende.

Alteration. The diopside shows all degrees of alteration to hornblende. Some sections show no alteration whatever; others contain traces of hornblende beginning to form along the cleavage planes in the diopside; others exhibit diopside in shred-like masses surround--ed by hornblende. Where the alteration has progressed still further, the merest traces of diopside remain and in some specimens alteration is complete. The alteration is often accompanied by the production of magnetite, and in many sections its presence is the only remaining indication that the hornblende present was once diopside.

A small part of the biotite is the result of the alteration of diopside. No alteration of aegerite-augite to amphibole has been observed.

MICA. Biotite. Biotite is the only original mica present. The color varies from dark brown to dark olive brown in the direction of the maximum absorption, and is straw yellow in the direction of minimum absorption. Almost all the biotite contains very slender needles of rutile intersecting at an angle of 60°. A small part of it is derived from diopside, as it can be observed forming in the cracks of that mineral. Most of it, however, appears to be an original product of the crystallization of the magma.

Alteration to chlorite is common, and the contact between biotite and magnetite frequently forms the locus for the formation of epidote.

AMPHIBOLE. Hornblende. The evidence that much of the hornblende has been derived from diopside has been presented under the discussion of the pyroxenes. In a few cases a zone of hornblende surrounds diopside with sharp contacts between the two, and the diopside is so fresh that it evidently has undergone no alteration. Fine idiomorphic crystals of hornblende occur entirely enclosed by single crystals of feldspar. These things make it seem probable that part of the hornblende is original, but there is no doubt that most of it is secondary. In the dike rocks much if not most of the hornblende is clearly primary.

The optical properties of the two types of hornblende are those of the common green variety. The pleochroism is: X = light brownish yellow, Y = yellow green, Z = dark olive green, $X > Y > Z$. $Y \parallel b$, $Z \wedge c = -18^{\circ}$. Its optical character is positive (+).

QUARTZ. The syenite contains quartz in only a few places, mainly in its border phases. It was the last mineral to crystallize from the magma, and all other minerals are idiomorphic in relation to it. The lines of contact between the quartz and the feldspars are never sinuous, being almost invariably perfectly straight lines corresponding to crystal faces of the feldspars. This is clear evidence that there has been no corrosion or resorption of the feldspar by the silicic portion of the magma during the final stage of crystallization. The quartz contains remarkable numbers of liquid inclusions; these occurring not only in the usual irregular lines, but also in clouds and streams. A large proportion of these liquid inclusions contain gas bubbles and many of the cavities are negative quartz crystals. Strain shadows are very uncommon, and crushing of the

quartz is only local.

ACCESSORY MINERALS. The accessory minerals are apatite, magnetite, titanite, zircon, rutile and garnet.

Apatite. Apatite usually occurs as idiomorphic prisms without terminations, but part of it is in the form of irregular grains, the largest of which have a diameter of one or more millimeters. It is strikingly abundant in all parts of the syenite. A few crystals contain dark brown rods of an unknown mineral arranged parallel to the c axis.

Magnetite. Magnetite is very common and is the result of two periods of formation. That of the first period is always idiomorphic and was one of the first minerals to form from the magma. That of the second period occurs in masses and aggregates in hornblende, being the result of alteration of that mineral.

The magnetite does not appear to be titaniferous as no alteration to leucoxene has been observed, and a qualitative test for titanium gave negative results.

Titanite. Titanite is always present in conspicuous amounts. It occurs as beautiful idiomorphic crystals and as irregular masses with a diameter as great as two millimeters. Its color is a fine golden yellow to light golden brown, with faint pleochroism. The mineral is always fresh and unaltered, and no leucoxene has been observed. Titanite is later than the magnetite and frequently forms borders around the latter mineral.

Zircon. Zircon has been observed in only a few sections.

Rutile. Rutile is to be found in the biotite occurring in distinct needles lying in the basal plane parallel to three directions

intersecting at 60° and 120°.

<u>Garnet.</u> The black garnet melanite occurs in the more sodic phases of the syenite. Thin sections show that it occurs in irregular masses of dark brown color often possessing an outer border of lighter brown garnet. The grains inclose apatite and are intimately intergrown with titanite and show no alteration. The relationships to other minerals show it to be an original mineral.

<u>Secondary Components.</u>

The secondary minerals in the Snowbank Lake rock have all been mentioned in connection with the alteration of the original minerals.

<u>Mica.</u> Colorless mica occurs in much of the feldspar. It is probably paragonite since it is always the result of the alteration of soda feldspars. It forms plates varying from almost submicroscopic size to 0.5 mm. in length, frequently with beautifully sharp, clear-cut boundaries. It occurs most often in the more calcic plagioclase and in the interior portion of the zoned crystals. Microcline, albite and orthoclase show no alteration to mica.

<u>Feldspars.</u> Oligoclase resulting from recrystallization of original feldspar is often present. It occurs between the larger grains or even within them. These secondary crystals are fresher in appearance and slightly more alkalic in composition than the original ones.

Myrmekite. Myrmekite is very abundant, frequently occurring in zones or bands running entirely across a section. This is an intergrowth of feldspar and quartz that will be discussed in greater detail in the section on rock structure. (See p.

Epidote. Epidote is very common in the various phases of the syenite and in all the dike rocks associated with it. Most of it occurs in irregular masses that are probably the result of the interaction of feldspar and a femic mineral, since most of it is found forming irregular masses around magnetite, biotite, or the pyroxenes. Thus it is evident that most of the epidote is secondary. In some of the dike rocks miarolitic cavities have their walls lined with epidote crystals with beautiful terminations. This indicates a pneumatolytic deposition later than the original crystallization of the magma, but different from the interaction mentioned above.

Some small dikes in the region are composed of idiomorphic hornblende crystals in a matrix of epidote. This suggests the pneumatolytic replacement of the feldspar resulting in an epidote hornblende rock.

The color of the epidote in the hand specimen is yellow, and in thin sections it is straw yellow to colorless, with the usual distinct pleochroism.

Calcite. Calcite occurs in very small amounts as a result of the alteration of the more basic plagioclase.

Iron Oxides. Magnetite forms small grains and clouds of minute particles in hornblende resulting from the alteration of pyroxenes. Limonite constitutes clouded masses in some of the more altered feldspars.

Chlorite. Chlorite is present in small amounts in much of the syenite, being most commonly a result of the alteration of biotite; but it is also derived from hornblende and possibly in a few cases directly from diopside. The biotite shows all degrees of altera-

tion to chlorite, much of it showing the normal green color, but possessing all the optical properties of biotite.

Fibrolite. Fibrolite occurs in many sections as inclusions in feldspar, being especially common in the non-striated albite. A large proportion of the fibers are parallel to the plane (110). It forms very slender fibers, colorless or pale yellow, with orthorhombic cross sections. Usually there is a parting perpendicular to the elongation of the fibers which are frequently curved or bent upon themselves. Alteration to a dark brown opaque substance is common.

III. PROMINENT TYPES OF THE SYENITE

A. Oligoclase Syenites

MICROCLINE-OLIGOCLASE SYENITE. A specimen collected on a shallow bay near the southwestern corner of Boot Island is an excellent example of the most prominent type of the syenite.

Description. Its texture is medium coarse, the grains averaging about 5 mm. in diameter, and its color is pale pinkish gray. The femic components are numerous, comprising green diopside and black hornblende. The feldspars are white or pale pink, and frequently the interior of the grains is pink and the exterior white.

Mineral Composition. Non-striated oligoclase is the principal feldspar, usually occurring as phenocrysts with intergrown lenses of microcline and albite. Much of this feldspar contains slender needles of fibrolite.

Microcline also occurs in large subhedral crystals that formed later than the microcline which is intergrown with the non-striated oligoclase. Striated plagioclase of about the composition $Ab_{84}An_{16}$ is present and is more altered than the other feldspars.

The hornblende is light green in color; most of it showing derivation from pale green diopside, residual portions of which can be observed in most of the grains.

Magnetite, titanite and apatite occur in numerous large grains.

The mineral composition calculated by the Rosival method as

Rosival, August, "Uber Geometrische Gesteinsanalysen," Verh. d. k. k. Geol. Reichsanst., p. 143, Wein 1898.

modified by Lincoln and Reitz is given below.

Lincoln, F. C., and Reitz, H. L., "The determination of the relative volume of the components of rocks by mensuration methods," Econ. Geol. Vol. 8, pp. 120-136, March 1913.

Microcline	20.6
Albite-oligoclase	48.6
Oligoclase	17.5
Hornblende	6.5
Diopside	2.6
Titanite	1.1
Magnetite	1.2
Biotite	0.5
Apatite	1.4
Total	100.0

The following analysis of a characteristic specimen of the rock was made by J. M. Lindgren, of the University of Illinois.

SiO_2	59.63
Al_2O_3	16.11
Fe_2O_3	4.87
FeO	0.87
MgO	3.16
CaO	5.02
Na_2O	5.83
K_2O	3.45
H_2O	0.78
TiO_2	0.62
P_2O_5	0.58
Total	100.65

The norm calculated from the above analysis according to the method adopted by H. S. Washington[1] is as follows:

1. Washington, H. S., Chemical Analyses Igneous Rocks, U. S. Geol. Surv. Prof. Paper 99, pp. 1162-1165, Washington, 1917.

Quartz		1.86
Orthoclase		20.02
Albite		49.26
Anorthite		7.78
Corundum		0.00
Salic	78.92	
Diopside		10.37
Hypersthene		3.00
Magnetite		0.93
Hematite		4.16
Illmenite		1.22
Titanite		0.00
Apatite		1.34
Femic	21.02	
Salic	78.92	
H_2O	0.78	
Total	100.72	

Class II. Dosalane
Subclass 1 Dosalone
Order 5 Germanare
Rang 2 Domalkalic monzonase
Subrang 4 Dosodic akerose.

QUARTZ-MICROCLINE-OLIGOCLASE SYENITE. A specimen collected on the east side of Snowbank Lake about one-fourth mile northwest of the northwest corner of sec. 32, T.63N., R.8W., is an excellent example of the quartz border phase of the syenite.

Description. This type of the syenite is a pale pink rock of medium grain containing a rather large proportion of femic minerals, pink feldspar, and a small amount of quartz.

Mineral Composition. The predominant feldspar is microcline in idiomorphic crystals, containing lenses of microcline and albite in smaller numbers than in the rock just described. It shows very distinct zonal structure, probably as a result of a larger proportion of soda microcline molecule in the nucleus.

Both striated and non-striated plagioclase also occur, the former near oligoclase, the latter approaching albite in composition. The oligoclase contains irregular patches of microcline but does not contain lens-like inclusions of that feldspar. A very large proportion of myrmekite has been formed in the microcline grains on their contact with oligoclase.

Diopside is almost colorless, showing only a slight green tint. Hornblende has begun to form in the interior and along the cracks of these grains. Magnetite is abundant and usually shows a striking ring of epidote that has formed on the contact with feldspars.

The mineral composition determined by the Rosival method is as follows:

Microcline	51.5%
Albite-oligoclase (Mostly striated)	24.0
Oligoclase (striated)	11.0
Quartz	5.0
Diopside	6.2
Hornblende	1.8
Apatite	0.1
Magnetite	0.2
Titanite	0.2
	100.0

B. Rocks of Boot Island.

The rock of the large central island of Snowbank Lake has a number of characteristics that differentiate it from the main syenite mass of which it is a part, in that it contains a larger proportion of the mafic minerals, biotite, hornblende, and diopside, and varies greatly in composition and texture within narrow limits. There are areas varying from a few inches up to many rods in diameter that have a dark color through the large content of mafic minerals. Sometimes these are irregularly winding streaks, or almost typical schlieren. They do not have the sharp contacts with the wall rock which is characteristic of the dikes of the area.

It is doubtful whether these local variations in composition are due to differentiation alone or to inclusion and digestion in the syenite magma of masses of greenstones. Greenstone fragments are found along the eastern border of the syenite that were carried up from below by the molten magma and highly metamorphosed. It is possible that in the hotter interior of the mass these fragments may have been completely digested. There is evidence of considerable movement after the mass had become viscous through partial cooling, and this would explain the narrow tortuous bands of more femic rock.

The dark femic phase of the syenite on the western side of the island is biotite diorite. It is probably a true differentiate since a gradual transition from silicic to femic rock can be traced.

The minerals in the Boot Island rock are not very different from those in the other portions of the syenite. The feldspars have the same character, but those occurring in the femic parts are more calcic, andesine being common. Biotite, hornblende and diopside are the characteristic femic minerals of this island, but there is a strong tendency for hornblende to be absent where biotite is present in important amounts. In one area the hornblende is brown rather than green, as it is in all the other portions of the region. The aegerite-augite where present is less of an emerald-green and more of an olive-green color than in the albite-aegerite syenite. (See p. 45.) Biotite occurs in very large flakes, up to 8 mm. in diameter.

Dikes are very common on the island. Red granitic dikes to be described later are rather evenly distributed throughout all the region, but pegmatite dikes are almost entirely confined to this one island, where they occur in great numbers. At several places on the island there are crushed zones where the syenite has been converted into a dark green rock with slaty appearance by the granulation of the feldspars and the development of chlorite.

Frequently crushed zones form the wall rock of dikes, and this is most often the case with pegmatite dikes.

PORPHYRY SYENITE. On the eastern side of Boot Island there occurs a porphyry syenite characterized by very large feldspar phenocrysts. It contains the same minerals as does the microcline-oli-

goclase syenite.

Description. The porphyry is a gray syenite, with idiomorphic phenocrysts having a maximum diameter of 25 mm., composing as much as 20 per cent of the rock mass. Its groundmass is medium-grained, with minerals having an average diameter of 2 mm. Most of the feldspars of the groundmass are gray in color, but a few are flesh pink. The femic minerals recognizable in the hand specimen are black hornblende and green pyroxene.

Mineral Composition. The phenocrysts are non-striated oligoclase albite, containing parallel lenses of potassic feldspar similar to those described before. Some of the included feldspar occurs in areas large enough to identify as microcline. The minerals of the groundmass do not differ from the same minerals in the more common syenite, except that the proportion of femic minerals is larger. The mineral composition of the porphyry determined by the Rosival method is as follows:

	Groundmass	Syenite including phenocrysts
Microcline	26.0%	28.5%
Oligoclase-albite (non-striated)	42.0	45.0
Oligoclase	4.0	3.2
Hornblende	11.5	9.6
Diopside	12.5	10.5
Aegerite-augite	1.5	1.2
Biotite	1.2	1.0
Titanite	0.7	0.6
Magnetite	0.4	0.3
Apatite	0.2	0.1
Total	100.0	100.0

On the eastern side of the island about twenty rods south of the porphyry syenite the proportion of green diopside in the biotite hornblende syenite is high, as is shown by the following percentage composition.

Non-striated oligoclase)	intergrown	49.5%
Microcline)		19.4
Diopside		21.0
Biotite		4.1
Magnetite		2.6
Titanite		1.3
Apatite		2.1
Total		100.0%

In this phase of the rock the feldspars are intergrown as usual, but there is good evidence that the proportion of potash increased as crystallization progressed. The lens-like areas of microcline increase in number on the margins of the grains, and borders of microcline surround the idiomorphic crystals of oligoclase. The large grains of diopside show hornblende forming along the cleavage cracks.

BIOTITE DIORITE. The most basic phase of the syenite magma on Boot Island occurs on the westernmost part of the island, where much of the rock is of this type.

Description. The rock is a very dark colored micaceous diorite, with the femic minerals biotite, diopside and hornblende predominating over the feldspars. The biotite flakes have a maximum diameter of 10 mm.

Mineral Composition. The feldspar is andesine and oligoclase-andesine, with a smaller amount of non-striated oligoclase-albite. Both these feldspars are considerably altered to mica with a small amount of iron oxides but there has been no recrystallization.

The other minerals in the order of their crystallization are apatite, magnetite, titanite, diopside, aegerite-augite, biotite, and hornblende. Much of the magnetite is enclosed by a narrow zone of titanite. The diopside is the pale green variety intermediate

between diopside and aegerite-augite. A small amount of aegerite-augite surrounds the paler variety of pyroxene. Biotite is the dark brown variety containing rutile needles. Hornblende occurs in large irregular grains. Its color is chestnut brown. X = yellow, Y = yellow brown, Z = chestnut brown, X>Y>Z, Z∧c: = 16°. The optical sign is positive (+). The optical properties and the brown color, shading to green on the border, indicate that this amphibole lies between common hornblende and barkevikite, characteristic of sodic rocks.

Because of the coarse grain and the large proportion of femic minerals in it, there has been notable alteration in this variety of the syenite. The alteration minerals are mica, calcite and iron oxides as mentioned under the feldspars, and in addition considerable amounts of epidote.

The mineral composition of the unaltered rock determined by the Rosival method is as follows:

Andesine	47.0%
Biotite	20.7
Hornblende	18.0
Diopside	7.7
Magnetite	2.5
Aegerite-augite	1.5
Apatite	1.7
Titanite	0.9
Total	100.0%

DIORITE. Near the southwest corner of Boot Island a point projects from the mainland into the lake. This is composed of a very dark femic rock, forming a ridge running to the southwest, disappearing in the swamp about a mile from the point.

Description. This rock is very hard and contains but few joint cracks, and is thus very resistant to glacial erosion. Its

contacts with the normal syenite are concealed by swamps on either side so that it is not known what the relations of the two rocks are. In color the diorite is dark gray to black, being formed of nearly equal parts of pale pink feldspar and black hornblende. Small amounts of biotite and quartz can be observed in the hand specimen. The average diameter of the components is 2 mm.

Mineral Composition. Common green hornblende is the predominant constituent. It is never idiomorphic in outline but forms irregular masses and grains with small grains of magnetite scattered through it. Many of the grains contain shred-like interiors of diopside which give evidence that the hornblende is derived from that mineral. The hornblende itself is partially altered to chlorite.

Biotite is present as an unimportant part of the rock, being olive-green in color, and quite generally altered to chlorite.

Plagioclase is the only feldspar present. Its index of refraction is always higher than that of quartz, and its optical character is usually negative (-), but is sometimes (+). Its angle of extinction at right angles to the plane (101) varies from 14^o to 22^o, indicating andesine to basic oligoclase with the composition $Ab_{60}An_{40}$ to $Ab_{70}An_{30}$. Much of the andesine is altered to mica and calcite.

A small amount of non-striated oligoclase is present and shows zoning, the large variations in the angle of extinction indicating a marked increase in the proportion of soda, as crystallization progressed.

The diopside is the pale green pleochroic variety that is

common to all the syenite.

The proportion of quartz varies from zero up to about 4 per cent. One specimen had none, another 2 per cent, and a third 4 per cent.. There is no indication of strain in the quartz grains and bubbles with liquid inclusions are numerous.

Magnetite occurs as very large crystals that formed near the beginning of crystallization, and as dust-like particles in the hornblende.

Titanite and apatite are similar to these minerals in the more acid syenite.

The secondary minerals are colorless mica, calcite, chlorite, and epidote.

The mineral composition of the rock is as follows:

Andesine	37.5%
Oligoclase	6.0
Diopside	1.0
Magnetite	5.5
Biotite	1.4
Hornblende	47.5
Epidote	0.5
Titanite	0.6
Total	100.0%

Origin. Three possibilities suggest themselves as to the origin of this diorite. It may be (1) a differentiate; (2) an intrusive; (3) a metamorphosed greenstone.

Greenstone fragments carried up from below and metamorphosed by the intruding syenite on the eastern side of the lake contain the following proportions of minerals:

Hornblende	68.0%
Biotite	17.4
Oligoclase	14.0
Diopside	2.2
Magnetite	0.4
Total	100.0%

The diorite resembles metamorphosed greenstone in some ways, but the latter rock is very much more femic. The diorite contains 56.5% mafic minerals, but certain of the altered greenstones studied contain 86% mafic minerals. The diorite contains the same type of non-striated oligoclase as the ordinary syenite and considerable titanite, while the greenstone contains neither. The minerals of the diorite are all idiomorphic in relation to the quartz with perfectly straight boundary lines corresponding to crystal planes, giving clear evidence that the quartz formed last and crystallized from a liquid condition. For these reasons it is concluded that the diorite is not metamorphosed greenstone, though it may possibly be the result of the crystallization of molten material that had assimilated much of the greenstone. Even this latter assumption seems somewhat doubtful, as the observed proportion of mafic minerals would necessitate the complete assimilation of about an equal mass of greenstone by the normal syenite. On the borders where the syenite is in contact with other rocks it shows a complete lack of assimilative powers.

The diorite lies in close proximity to the biotite diorite described in the last section (p. 38), and has many characteristics in common with the later rock, which is undoubtedly a true differentiate since a gradual transition to normal syenite can be traced.

It seems very probable therefore that the diorite also represents a marked case of differentiation, that may have resulted through the sinking of heavy mafic minerals formed early in the process of crystallization of an acid magma in the way suggested by Bowen.[1]

1. Bowen, N. L., "Later Stages of Evolution of Igneous Rocks," Sup.

Journ. Geol. Vol. XXIII., pp. 1-91, 1915.

C. Albite Syenites

Around the southern bay of the lake and extending to Round Lake and occupying almost all of the region between the two lakes, is a mass of syenite which differs from the more common phase of this rock in that it is more strongly alkalic. It is not known certainly whether it is an alkalic differentiate of the main mass of the syenite, or whether it is slightly later in age, being formed from material that had undergone differentiation previous to injection. The presence on Boot Island of albite syenite dikes, and the work of Bowen makes the latter view seem the more probable, however. If there is a surface of contact between the two phases it is concealed lying under the waters of the lake for most of its length.

Distribution. The albite syenite is variable in all its characteristics and the occurrences will have to be described individually. Between Snowbank and Round lakes in the northern part of the area the rock is quote uniformly a fine-grained pale flesh-colored syenite, sometimes containing quartz. Along the outer border its character changes within short distances, and here it is usually quite coarse-grained. It often shows gneissoid structure due in some cases to the parallel arrangement of the feldspars, and in others to parallel bands of mafic minerals.

Description. The color of the albite syenite varies from pale flesh pink to red, and the diameter of the individual grains from 1.5 to 10.0 mm. Green diopside, black hornblende, and feldspars showing carlsbad twinning can be distinguished in the hand specimen; the feldspars are most often pale pink, but white feldspar is common

and jet black garnets and quartz occur locally. This phase of the syenite is in contact with the gabbro and has been metamorphosed to a rock that looks much like granulated gabbro.

Mineral Composition. The rock is characterized by a total absence of recognizable microcline grains, a very small proportion of orthoclase, an excessive amount of non-striated albite containing very minute indistinct lens-like inclusions of potassic feldspar and a small amount of striated albite-oligoclase. The albite composes from 50 to about 90 per cent of the rock mass and zonal variations in composition are more common than in the microcline-oligoclase phase of the syenite. No phenocrysts show in the hand specimen, but the microscope reveals two generations of feldspar. The earlier generation is non-striated albite, which usually contains intergrowths with potassic feldspar. The interior calcic portion frequently shows partial alteration to mica. The later generation of feldspar is more often striated and the small amount of orthoclase appears to belong to the same generation of crystals.

The striated plagioclase has a maximum angle of extinction of 7°30' perpendicular to the (010) plane, indicating a composition of about $Ab_{85}An_{15}$.

A gray pink very feldspathic specimen collected about an eighth of a mile south of the southern end of the lake and near the section line between secs. 11 and 12 T.63R.9, was crushed and the feldspars studied by the Shuster method. The optical character was usually plus (+), and the index of refraction was always distinctly lower than that of balsam. The extinction angles on (001) were 3° to 4°, and on (010) varied from 12° to 16°. The bisectrix emerged perpend-

icular to the cleavage in plates parallel to (010). This indicates a plagioclase having a composition between $Ab_{86}An_{14}$ and $Ab_{94}An_6$.

Schuster, Max, Mineralogische und Petrographische Mittheilungen Band 5, pp. 937-404, Wein 1883.

The fact that the bisectrix emerges perpendicular to (010) allows the use of the method of Fouque to check these results. This in-

Fouque, Ferdinand A., "Contrib. a l'etude des felspaths des roches volcanique," Bull. de la Societe Mineralogique de France, Vol. XVII., p. 306, Paris 1894.

dicates that the non-striated plagioclase has a composition of about $Ab_{90}An_{10}$ to $Ab_{94}An_6$.

Most of the albite contains very minute parallel lenses of potash feldspar. These are smaller and less distinct in outline than the intergrown feldspar of the normal syenite, but there can be no doubt that they are similar in composition.

The orthoclase is slightly clearer than the albite, and the index of refraction is slightly lower. The crystals are subhedral in outline but are rounded as if there had been some resorption and they appear slightly older than the albite crystals.

Soda microcline without recognizable grating structure is probably present in indeterminable proportions.

The absence of twinning striations in many of the feldspars prevents a determination of their relative proportions in the rocks since the differences in the indices of refraction are not great enough to distinguish them in all positions.

The femic minerals are diopside, aegerite-augite, hornblende, magnetite, and titanite as in the microcline-oligoclase syenite, and black garnet which is not known in that rock. In the albite

phases of the syenite femic minerals are usually present in limited proportions and in some areas feldspar forms 92% of the rock mass. The green diopside showing a notable proportion of acmite molecule is inconspicuous or totally absent in such feldspathic types as is hornblende.

Aegerite-augite occurring in grains with a straw yellow and emerald green pleochroism is a common constituent in this type of the rock and is the only femic component among the essential minerals in some areas. The color of the diopside and the large amount of aegerite-augite shows that the pyroxenes are rich in soda, as would be expected from the high soda content of the feldspars.

The garnets that appear black in the hand specimen are medium to dark brown under the microscope. Their color indicates that they are melanite which is characteristic of very alkalic rocks. The exact period of crystallization of the garnet cannot be determined but it appears to have been a little later than the aegerite-augite which is included by the garnet.

Biotite is present, but is not as abundant as in the other phases of the syenite. Titanite and apatite are even more abundant than in the more common syenite and occur in very large masses and crystals. Magnetite is scarce.

The secondary minerals, chlorite, epidote, mica and iron oxides occur about as in the microcline syenite. Calcite is found in a few specimens.

AEGERITE-AUGITE PHASE. The specimen mentioned on page represents a type of the albite syenite common around the southern bay of Snowbank Lake and extending east toward Round Lake and south

to the Duluth gabbro.

The hand specimen reveals large pink feldspar crystals having a maximum length of 25 mm. and width of 8 mm. showing parallel arrangement and carlsbad twinning. Black pyroxene is the only femic component recognizable.

The optical characters of both the albite and the aegerite-augite have already been described. Part of the small feldspar grains are optically negative (-). Their cleavage is very imperfect and the angles of extinction cannot be observed. This feldspar is slightly more limpid than the non-striated plagioclase. These characteristics and the presence of a larger amount of potassium in the chemical analysis (see p. 47) than can be accounted for by the orthoclase, indicates that it is a soda microcline with submicroscopic grating structure.

Iddings says of soda microcline, "In potash-soda-feldspars

Iddings, J. P., "Rock Minerals," p. 235, John Wiley & Sons, New York 1911.

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rich in soda there is extremely minute to almost submicroscopic multiple twinning as in microcline. But the lamellae are generally more minute and in some cases are only recognizable in extremely thin section..........

"In some of these feldspars there is a small amount of lime, but as they are often perthitically intergrown with lime-soda-feldspar it is not always certain in what way the lime occurs."

Only a few grains of striated oligoclase are present, and these are much altered to an aggregate in which colorless mica is the prominent component. Orthoclase is present but unimportant.

Aegerite-augite is the principal dark component, and occurs as

beautiful idiomorphic crystals perfectly fresh and unaltered. The pleochroism is striking, in colors from straw yellow to clear emerald green.

A very few grains of olive green biotite are present. Titanite is common and is similar to that described before. Magnetite forms a few small grains, and apatite is very abundant. The dark components often occur in groups, and magnetite, apatite, titanite, garnet and to a smaller extent feldspar are included in the larger grains of aegerite-augite.

The black garnet, melanite, common in very sodic rocks, is present in this specimen of the syenite.

The mineral composition is as follows:

Albite) Soda-microcline)	87.0%
Aegerite-augite	4.0
Orthoclase	3.0
Striated oligoclase	2.0
Black garnet	2.4
Titanite	0.7
Apatite	0.6
Magnetite	0.3
Total	100.0%

A partial analysis of the same rock was made by J. M. Lindgren with this result:

SiO_2	60.70%
CaO	4.89
MgO	1.56
Na_2O	4.58
K_2O	6.82
Total	78.55%

A calculation of the sodium and potassium to feldspar shows that the albite and orthoclase molecule would be present in about equal amounts, but the microscope does not reveal potassic feldspar in amounts nearly equal to albite. It seems probable that the al-

bite contains important amounts of potassium.

On the north side of Round Lake occurs a phase of the syenite very much like that at the south end of Snowbank Lake except that it contains some diopside. The feldspar is all intergrown albite and microcline in the form of parallel lenses. The only femic mineral of importance is a pyroxene intermediate between diopside and aegerite-augite. Its outer part is grass green and its inner portion pale green, with an angle of extinction varying from 39° in the interior to 55° in the outer border.

The composition of this rock is as follows:

Albite) intergrown	41.4%
Microcline)	23.6
Diopside (acmite rich)	33.0
Magnetite	0.8
Apatite	0.7
Titanite	0.5
Total	100.0%

Another feldspathic rock from the same region is composed largely of idiomorphic albite grains with quartz forming very narrow films in the spaces between the grains. (See Plate III.-A)

<u>Garnetiferous Variety.</u> A specimen collected on Round Lake near the outlet of the stream that drains that lake into Snowbank Lake, is a pale pink syenite like most of that in this part of the region, but areas up to 0.1 meter in diameter are studded with black garnets that form as much as a third of the rock mass. Between these areas the garnets are less numerous.

Albite is the principal feldspar, but this is much altered to mica and iron oxides. The garnet, melanite, occurs in two colors, the one light brown and the other dark brown. The garnets inclose titanite, apatite, and aegerite-augite. Titanite, magnetite, and

apatite have the same properties as in other varieties of the rock.

DIOPSIDE PHASE. A specimen collected near the head of the southeast bay of Snowbank Lake in the southwest corner of sec. 32, T.64N., R.8W., probably represents a local coarse-grained phase of the albite syenite. This rock shows a definite contact with the quartz phase to be described later (p. 52) and there are indications that it is intrusive in the microcline-oligoclase syenite.

The rock is very coarse-grained, and is dark pink in color. Its feldspars frequently show carlsbad twinning, and the larger ones are zoned, the interior of the grains being gray and the outer zones pink. Their average diameter is 5 mm. Diopside and biotite are the mafic minerals recognizable in the hand specimen, and occur in large aggregates.

This rock is composed of a very intricate intergrowth of feldspars. Lens-like areas of very small size are present, but these show all transitions to large irregular areas of potassic feldspar, probably microcline or soda microcline. The different grains are dovetailed into one another at the boundary in a very complex manner. Small irregular areas show alteration to mica, and zonal interiors are altered to an aggregate in which colorless mica is the most conspicuous component. The proportion of potassic feldspar is hard to estimate, but it composes less than one-third of the grains. Almost no striated plagioclase is present.

The diopside is pale green with a distinct pleochroism. The biotite is olive brown with inclusions of rutile needles. It is often partially altered to chlorite. Titanite, magnetite, and apatite occur abundantly and in very large grains. The proportion

of the various components is as follows:

Albite (intergrown with microcline)	77.0%
Biotite	7.0
Diopside	4.0
Magnetite	0.7
Titanite	0.9
Apatite	0.4
Total	100.0%

HORNBLENDE PHASES. A fine-grained type extends from a point near the middle of the western boundary of sec. 32, T. 64, R. 8, around the head of the bay on the southeastern side of Snowbank Lake to about the middle of the northern side of sec. 31. On the north is soda syenite just described, and on the northeast is the quartz-rich phase that appears to intrude both the syenites.

This is an even grained, pale flesh-pink variety. The average diameter of its components is about one millimeter. Black minerals with parallel arrangement give the rock a slightly gneissoid structure.

In most of the specimens the feldspars are complex intergrowths of albite and potassic feldspar, probably soda microcline. There are phases characterized by diopside and others by hornblende derived from diopside. A small amount of biotite is present in the rock. Magnetite, titanite and apatite occur about as in other varieties of the syenites. The following is the mineral composition of this type.

Albite	60.0%
Oligoclase	25.0
Quartz	7.4
Hornblende	5.5
Magnetite	0.9
Titanite	0.8
Apatite	0.4
Total	100.0%

In other specimens the proportion of the minerals is about the same but the quartz is usually absent, and often diopside occurs instead of hornblende.

FELDSPAR ROCK. A gray rock occurring about 90 rods north of the southeast corner of sec. 31, T. 64, R. 8, near the eastern shore of Snowbank Lake is microscopically similar to most of the other syenite of the region but it is almost completely lacking in dark components. Under the microscope it is seen to be composed mainly of non-striated albite in idiomorphic crystals showing marked zoning. There is a very small amount of potassic feldspar present in the form of isolated lenses in the albite. Striated plagioclase occurs in limited amount with angles varying from 4° in the center up to 15° on the outer margin of the same crystal, and indicates that the first plagioclase to form was near oligoclase and that the latter was albite-oligoclase. All the feldspars are very clear and glassy, and they contain only small amounts of mica. Hornblende and diopside are present in very small quantity.

Part of the hornblende is derived from the diopside which still forms the nucleus of most of the grains. Some of it, however, seems clearly to be primary as idiomorphic crystals are entirely enclosed in single crystals of feldspar, and part of these inclosed grains of hornblende show fine zonal structure. (See Plate IV. B.)

IV. GRANITE.

In the region between Snowbank, Round and Disappointment lakes there is an area of granite that is intrusive into the syenite, and which probably is of the same age as the granite dikes that cut all the rocks of the region. This is the only Snowbank intrusive that is high in quartz or is uniformly quartz-bearing. This granite is unusually well exposed as there is very little timber and moss in this region, and areas as much as an acre in extent are perfectly bare. The whole mass is about 80 rods in diameter, and is very uniform in all its characteristics.

Description. The granite is rather fine-grained, being composed of grains with an average diameter of 1.5 mm. Its color is pink, and its predominant feldspar is pink; but a small amount of white feldspar is present.

Mineral Composition. Non-striated albite is the predominant feldspar, but oligoclase-albite showing a few striations is an important component. The albite is zoned with a more acid outer border; and with the interior frequently altered to mica. Much of the feldspar is idiomorphic. The femic minerals are brown biotite, now partially altered to chlorite, a small amount of green augite between diopside and aegerite-augite in composition, magnetite and a little titanite. The quartz is very clear and glassy, showing no crushing, or strain shadows. Liquid inclusions and gas bubbles are abundant and many of these cavities have the shape of negative quartz crystals. All the minerals are idiomorphic in their relation to the quartz, which was the last mineral to form.

Its mineral composition is as follows:

Albite	47.0%
Oligoclase	15.0
Quartz	34.0
Biotite	2.5
Green Diopside	1.0
Titanite	0.5
Total	100.0%

V. DIKE ROCKS.

The dike rocks of the Snowbank Lake region comprise a large number of varieties which may be considered in groups, the members of which show transition from one to another.

The most important and widespread group is that of the aschistic dikes, which includes red and gray granite dikes and syenite dikes. These exhibit both granitic and porphyritic structures. Closely related to the aschistic dikes is the highly quartzose granite near the east side of Snowbank Lake.

The diaschistic group comprises pegmatites, aplites, and lamprophyrs. The aplite dikes include aplites, bostonites and malchites. The porphyry on the western side of the lake belongs to this group. Lamprophyrs are the least common type and include augite kersantites and rocks near spessartites in composition.

A. Aschistic Dikes

GRANITES. The most widely distributed dikes in the Snowbank Lake region consist of granite. These cut all the different phases of the syenite, and extend far into the metamorphosed sediments especially on the eastern border. They vary in size from the smallest stringers up to a foot or more in width. (See Plate VIII. B.) The contact between dike and wall rock is rather sharp, and the dikes are nearly straight, but irregular stringers are present. They cut the syenite impregnated sediments on the west side of Snowbank Lake, even splitting boulders included in the Ogishki Conglomerate. They are later than the diorite on the point southwest of Boot Island since they cut it; and they were observed to cut some of

the pegmatite dikes on Boot Island. Their time relation to the more basic dikes is not clear.

The color of the rock in this type of dike is most often pink or red, but in a few dikes the rocks are pale pink and in others are gray. In one dike the rock is nearly white. The size of the grain varies greatly, ranging from 1 to 10 mm. in diameter. Phenocrysts are not observable in the hand specimens but two generations of feldspar are discernible under the microscope.

Red Granite. A two-inch dike cutting the diorite on the headland just south of Boot Island represents a type of dike very close in composition to the normal microcline syenite of the region.

The feldspar consists of striated plagioclase, non-striated albite, and microcline. Quartz forms nearly one-third of the rock mass, and biotite a very small proportion. Microcline is the predominant feldspar, occurring in anhedral grains of varying size. It is intergrown with soda feldspars to a small extent, and less often is intergrown with quartz to form a coarse micropegmatite.

The striated plagioclase, near oligoclase in composition, occurs in large idiomorphic phenocrysts of an older generation than the microcline, and the more sodic plagioclase of the groundmass. These are much altered to colorless mica and the mica plates are very large reaching a maximum length of 15. mm. A very narrow unaltered zone surrounds the altered portion of the crystals.

The clear unaltered plagioclase of the groundmass has a maximum angle of extinction of 16° perpendicular to the plane (101), indicating albite of the composition $Ab_{95}An_5$, and is similar to that in the normal syenite.

The quartz was the latest mineral to crystallize since all the feldspars are idiomorphic in relation to it. It contains large numbers of liquid inclusions frequently containing gas bubbles, and many of the cavities are negative quartz crystals.

Biotite now largely altered to chlorite is an unimportant part of the rock. Apatite and magnetite are present in small amounts.

The alteration minerals are colorless mica, epidote, and a small amount of iron oxides.

The mineral composition of this rock is as follows:

Quartz	28.0%
Albite	30.5
Microcline	36.0
Non-striated albite	4.5
Chlorite	1.0
Total	100.0%

Like many other dikes of the region it shows evidence of crushing and this phenomenon will be discussed in more detail in the section on rock structure.

The type of dike mentioned above is very similar to the quartzose granite in the area between Snowbank, Round, and Disappointment lakes, which appears to be younger than the normal syenite. It seems probable that the dikes of this type are closely related in mode and time of origin to the granite.

Gray Granite. Dikes of this type have the typical granitic structure, but contain a larger proportion of dark components than the rock just described. The feldspar is nearly all non-striated albite often much altered to colorless mica. The hornblende is pale green, occurring in aggregates and in idiomorphic crystals. Titanite is very abundant and occurs in fine idiomorphic crystals. The

mineral composition is as follows:

Quartz	22.0%
Non-striated albite	69.0
Hornblende	6.4
Titanite	1.6
Magnetite	0.4
Apatite	0.6
Total	100.0%

GRANITE PORPHYRIES. Many of the granite dikes of the region are porphyritic. They include red and gray varieties, and are closely related to the granites, differing from them mainly in structure. They show all degrees of transition to granite dikes of similar type on the one side and to aplite dikes on the other.

Red Granite Porphyry. Microcline is the predominating feldspar, with smaller amounts of striated oligoclase, and non-striated albite. In typical specimens quartz forms about 30 per cent of the rock mass, and a very small amount of magnetite is the only dark component. The groundmass comprises about one fourth of the rock mass, with quartz in about the same proportion as in the phenocrysts. Many of the microcline phenocrysts are intergrown with quartz on the outer margin forming a zone of micropegmatite running out into the surrounding groundmass. The oligoclase, and to a lesser extent, the non-striated albite of the groundmass shows alteration to colorless mica, and the phenocrysts of feldspar are very much altered to the same mineral. A few phenocrysts of biotite are entirely altered to chlorite.

Gray Granite Porphyry. This type of dikes is well represented by a specimen collected on the eastern side of Boot Island.

The dike was about four inches in width. The groundmass is of very fine-grained lithoidal texture and the color is gray. The

phenocrysts are white feldspar, idiomorphic in outline and having a maximum diameter of 6 mm. Somewhat smaller phenocrysts of black hornblende accompany the feldspar.

The groundmass comprises 68 per cent of the rock volume. The average diameter of the mineral grains of the groundmass is between 0.01 and 0.02 mm. The minerals forming the groundmass and their proportion are given below:

Quartz	27.0%
Albite	8.0
Microcline	53.0
Hornblende	8.0
Biotite	3.0
Apatite	0.7
Magnetite	0.3
Total	100.0%

Plainly the groundmass of the rock is less like the gray granite than it is like the red granite (p. 56).

The quartz shows strain shadows in most cases but there is no evidence of crushing. The feldspar of the groundmass shows distinct zoning, indicating an increase in the acidity even while the groundmass crystallized. Biotite flakes vary greatly in size and some of these are almost as large as the other phenocrysts. The hornblende is of the normal green variety. The size of the grains varies in diameter from 0.02 to 1.5 mm. The hornblende is later than the biotite, as large idiomorphic flakes of the latter are included in the larger crystals of hornblende. Since the hornblende crystals occur in both the groundmass and as phenocrysts its period of formation must have extended over a long time. In the groundmass it is often shredlike, but in the phenocrysts it is usually idiomorphic.

The feldspar phenocrysts are oligoclase now much altered to

mica, and clear glassy crystals of non-striated albite. Many of the phenocrysts of the latter feldspar contain a small nucleus of striated feldspar. Zoning is prominent and the idiomorphic outline is extremely perfect. The zoning indicated that there were fluctuations as the crystals grew and that at nearly the end of crystallization there was a sudden change probably corresponding to the formation of the groundmass, producing very acid feldspar. The inner zones have a rounded outline indicating that there was resorption and then redeposition of material. Carlsbad twinning is very common.

The hornblende forms about 10 per cent of the phenocrysts; some of it is in the form of needles, some in idiomorphic crystals, and much of it is in masses or aggregates. The larger crystals contain much biotite in greenish brown idiomorphic flakes.

Granite Porphyry of Doubtful Relations. On the western side of Snowbank Lake occurs a gray granite porphyry, very similar to that of the dikes just described. It is discussed here because of its similarity to the porphyry of the undoubted dikes.

This porphyry contains large phenocrysts of white or pale pink feldspar, 1.0 to 10.0 mm. in length and a fine-grained, dark gray groundmass, containing needles of black hornblende, some of which are as large as the phenocrysts of feldspar.

Phenocrysts of feldspar constitute 11 per cent of the rock mass and hornblende 6 per cent. The feldspar is oligoclase, much altered to colorless mica, and is always idiomorphic. The hornblende is in idiomorphic crystals with ragged borders like those described in the malchite. (See p.

The groundmass has a granitic structure and differs from that of the malchites which have almost a diabasic structure, but one type seems to grade into the other. It is composed of sodic and potassic feldspars, a small amount of quartz, and hornblende needles. The average diameter of the grains of the groundmass is 0.03 mm. The hornblende is poikilitic, enclosing feldspar similar to that in the groundmass. The ragged border is due to the addition of material after the groundmass began to form and is illustrated in Plate IV. fig. A. Zonal structure is present in the larger crystals, with a pale green interior and a darker green exterior, and twinning is common. The border of the feldspar phenocrysts is ragged, due to the same addition of material to the phenocrysts after the groundmass began to form. Quartz is not common in the groundmass and only a very few quartz crystals reach the size of small phenocrysts.

Age Relationships of the Porphyries.--The relationship of this porphyry on the west side of the lake is not clear, as no contact has been observed. It may be an intrusive slightly different in age from the syenite, or it may represent its upper quickly-chilled portion.

Elftman[1] concludes that this porphyry is older than the syenite

1. Elftman, A. H., 22nd Ann. Rep. Geol. and Nat. Hist. Surv. of Minn. p. 122, Minneapolis 1893.

It is true, as he says, that the porphyry is older than the granite dikes, but these same dikes cut all phases of the syenite itself, and are evidently one of the latest manifestations of igneous activity of the region. For this reason they can not be taken as evidence of the relative age of the porphyry and the syenite. If the

normal sequence of igneous injections were followed, hornblende porphyries should be the result of magmatic differentiation of a syenite magma and would be later than the syenite. Porphyry dikes are common in all the region between Snowbank Lake and the area of Giant's Range granite on the Kawishiwi River and it may be that these dikes are to be correlated with the Giant's Range granite and so may be older than the Snowbank Lake syenite. This does not seem probable, however, as it necessitates an assumption that the granite is older than the syenite, followed by an assumption that the dikes are offshoots of a distant igneous mass.

SYENITE. In the syenite on Boot Island there are dikes very similar to the albite syenite occurring in the southern part of the region. Their color is flesh-pink and their feldspar crystals are large, reaching a length of 1 mm. There is a total absence of quartz, a small proportion of mafic minerals and a large proportion of sodic feldspar as in the albite syenite. These dikes differ from the albite syenite only in containing a few crystals of microcline. There is a gradual transition from the sodic syenite of the dike to the wall rock with indications that the sodic phase intruded the older darker one before the latter was entirely cold.

A dike of the same type, occurring on the north side of Boot Island is composed of white feldspar and a small amount of black biotite in flakes 1 mm. in diameter, forming a nearly white rock. Under the microscope it is seen to consist of two-thirds plagioclase and one-third microcline, with about 3 per cent of biotite. The plagioclase has an index of refraction very little higher than that of balsam, and an angle of extinction of about +3° indicating oligo-

clase of about the composition $Ab_{77}An_{23}$. Part of the plagioclase is in the form of phenocrysts intergrown with microcline. The borders of the crystals contain parallel intergrowths of sodic and potassic feldspars. Accessory minerals are apatite and titanite.

B. Diaschistic Dikes.

PEGMATITE. Pegmatite dikes are most common on Boot Island near the center of Snowbank Lake. They vary from a few inches to several feet in diameter.

They are composed of pink feldspar and quartz. The feldspar is frequently intergrown with quartz, and milky quartz forms large vugs in the center of the dikes. Very often the wall rock has been crushed by movement before, or during, the intrusion of the dike, as indicated by distorted feldspar crystals. (See Plate III. A.)

The feldspars are perthitic intergrowths of microcline and sodic plagioclase. The quartz is intergrown with the perthitic feldspar to form a coarse-grained micropegmatite. The plagioclase is non-striated and is in all ways similar to the non-striated albite of the syenite. The complex nature of the intergrowths of the feldspars makes accurate determination of the relative proportions difficult, but the microcline and non-striated albite appear to be present in about equal amounts. No femic minerals are present.

APLITES. Fine-grained lithoidal rocks with a diabasic structure are very characteristic of the west end of Snowbank Lake and the region between that lake and Moose Lake. They were called diabase by N. H. Winchell[1] but, even according to his determinations

1. Winchell, N. H., Final Rep. Minn. Geol. and Nat. Hist. Surv., Vol. V., p. 773, St. Paul 1899.

they contained oligoclase and quartz. They were evidently classified on the basis of structure and not on mineral composition.

Granite Aplite. The granite aplite dikes are very similar to the granite dikes and in fact one type grades into the other. Like the granite dikes they are red in color.

The most characteristic specimens are composed of striated albite, non-striated albite, and quartz in about the following proportions:

Striated albite	48.0%
Non-striated albite	20.0
Quartz	30.0

The remaining 2 per cent is apatite, a small amount of magnetite, and some chlorite. The striated plagioclase has an extinction of about 15°30' perpendicular to the plane (101), indicating albite of the composition $Ab_{95}An_5$.

The feldspars contain the usual flakes of secondary mica, and small amounts of iron oxide.

Quartz Bostonite. The quartz bostonite dikes are well represented by a specimen collected about half way between Flask and Lost lakes. The rock has a dark gray color and is saccharoidal in texture. The structure often closely resembles that of diabase. Feldspar and a small amount of pyrite are the only minerals to be observed in the hand specimen. The feldspar occurs in lath-shaped crystals, having a length of about 0.12 mm. The angle of extinction indicates oligoclase of about the composition $Ab_{85}An_{15}$. A small amount of non-striated albite is present in the rock. Scattered grains of quartz, having about the size of the feldspar laths occur as phenocrysts, but most of the quartz is in the form of

interstitial micropegmatite. Hornblende, colorless mica, titanite, pyrite and epidote constitute the other crystals of the groundmass. The colorless mica forms part of the groundmass but the same kind of mica has formed within the oligoclase through alteration, where it occurs in very clear cut flakes up to 30 mm. in length, inclosed in oligoclase that shows very little alteration.

Other dike rocks near the west end of the lake are similar to that just described, but usually they have little quartz, and lack the interstitial micropegmatite described above. A few phenocrysts of non-striated albite and hornblende occur in them, but the great mass of the rock is composed of laths of acid oligoclase.

Bostonite. The bostonite dikes are all very fine-grained, of lithoidal or felsitic appearance. Their color is gray and only a few phenocrysts of non-striated albite and of hornblende are present. Those of hornblende are slightly more common than those of feldspar. The structure of many of these dikes is diabasic or closely approaches it. The only difference between them and the quartz bostonite dikes is in the proportion of quartz present.

A specimen collected on Snowbank Lake near the end of the portage between that lake and Moose Lake is typical. It is composed of laths of oligoclase feldspar and a very small amount of quartz. The length of the laths varies from 0.1 to 0.15 mm. Other minerals of the groundmass occurring in small amounts are hornblende, muscovite, apatite, titanite, and magnetite, now altered to hematite. There is a little very fine-grained micropegmatite between some of the laths of oligoclase.

The phenocrysts are very few in number, and consist of hornblende and non-striated albite both showing distinct zoning.

Malchite. By an increase in the proportion of hornblende and the presence of more basic feldspar the bostonite passes over into malchite, dikes of which are common around the east side of Flask Lake.

A characteristic specimen of the rock is dark greenish gray, with idiomorphic crystals of white feldspar up to 5 mm. in diameter, and of black hornblende, 2 mm. in diameter in a fine-grained groundmass that is very dark, almost black in color.

Hornblende phenocrysts, composing about 28 per cent of the rock, are idiomorphic and usually have ragged borders. Many of the crystals show marked zonal structure, with the interior composed of a very pale green hornblende and the exterior of a dark green variety. (See Plate IV.-A and B.) The change from one color to another is not gradual but is very sharp, indicating a sudden change of conditions as crystallization progressed. Twinning is very common. They have ragged outlines that appear to be due to the addition of material to the crystals after the groundmass of the rock began to solidify. The feldspar phenocrysts which form not more than 8 per cent of the rock mass are plagioclase, much altered to aggregates of colorless mica and here and there containing radiating masses of blue tourmaline.

The groundmass consists of grains of feldspar, varying in size from 0.03 to 0.3 mm. and of flakes and needles of hornblende. Part of the feldspar is near andesine in composition, idiomorphic laths are present, but the greater portion of the feldspar is anhedral. All the feldspar of the groundmass contains numerous flakes of mica, but except for the formation of these flakes it is unaltered. Horn-

blende forms 20 per cent of the groundmass, and is the same color as that in the phenocrysts. Accessory minerals are apatite, titanite, magnetite, and epidote.

Another specimen, dark greenish gray in color, collected in the same vicinity, contains almost no phenocrysts of feldspar visible in the hand specimen, but much hornblende.

Under the microscope a few phenocrysts of plagioclase can be seen. The hornblende phenocrysts are paler in color and less perfect in outline than those described above, but are present in about the same proportion. The feldspar of the groundmass which **is idiomorphic,** is very fresh and has an angle of extinction of about -16° perpendicular to the plane (010), indicating andesine with a composition of about $Ab_{67}An_{33}$. In addition there are present a few grains of non-striated acid feldspar.

LAMPROPHYRES. <u>Augite Kersantites.</u> On the east side of Snowbank Lake and more especially around Disappointment Lake there occur dikes that have been grouped together by Clements[1] as being composed

1. Clements, J. Morgan, U. S. Geol. Surv. Mono. No. 45, pp. 372-373, Washington, 1903.

of lamprophyres. These are dark green, femic or intermediate rocks.

The dikes mapped by Clements on Disappointment Lake were not studied, but dark green dikes in the region between Snowbank and Disappointment lakes were found to consist of material that is very like kersantite.

Pale green diopside similar to that found in most of the syenite is its principal constituent. This is darker green on the outer border where it approaches aegerite-augite in composition. It is somewhat altered along the cleavage cracks to green hornblende.

Brown biotite is an important constituent and both this and the hornblende are partially altered to chlorite. The mineral composition is given below.

Andesine-oligoclase	14.0%
Potash feldspar	12.0
Diopside	28.0
Biotite	22.0
Hornblende	21.0
Total	97.0%

The remainder of the rock is composed of small amounts of titanite, much apatite, and a little magnetite. The index of refraction of the striated plagioclase is lower than that of balsam, and the angle of extinction at right angles to the plane (010) is about $+10^{\circ}$, indicating a composition $Ab_{73}An_{27}$. The potash-feldspar is like that in the syenite and has the same parallel intergrowths of feldspars. The striated plagioclase is in lath-shaped crystals but the potash-feldspar is in anhedral grains. Most of the diopside is in the form of idiomorphic phenocrysts. The titanite is of the same color and appearance as that found in the syenite.

Spessartite-like Rock. A peculiar lamprophy occurs on the east side of Snowbank Lake, on the section line 120 rods south of the northwestern corner of sec. 32, T. 64, R. 8. It strikes east and has a width of about two feet. This is a dark gray dike rock with large aggregates of black hornblende up to 2.0 mm. in diameter, in a gray groundmass of lath-shaped feldspars. Plagioclase is the most important component and occurs in idiomorphic crystals varying from 0.3 to 1.0 mm. in length. Zoning is very marked with the angle of extinction at right angles to the plane (010) varying as much as 18° in a single individual. The first feldspar to crystallize

possesses an angle of +12° and the last an angle and the last an angle of -10°, indicating that crystallization began with andesine of the composition $Ab_{72}An_{28}$, and ended with oligoclase-albite of the composition $Ab_{88}An_{12}$. In addition to the albite twinning most of the laths of plagioclase show Carlsbad twinning. A small amount of non-striated albite occurs in idiomorphic zoned crystals, that are thicker than those of the plagioclase and are slightly larger. All the feldspars are very clear and show little evidence of alteration, but small areas in both the striated and non-striated feldspars are altered to colorless mica, and contain slender needles of fibrolite.

Hornblende is the most important mafic mineral of the rock. It is the common green variety in idiomorphic crystals of about the same size as the feldspar. In addition many hornblende crystals occur in irregular aggregates, but these too are idiomorphic and show twinning. There is no trace of diopside and it is clear that hornblende is original since idiomorphic crystals show twinning and zoning. Biotite of the usual brown variety occurs in crystals of about the same size as the feldspar and hornblende. Accessory minerals are titanite, magnetite, apatite, and epidote, all similar to minerals of the same kind occurring in the syenite.

The minerals just described are surrounded by a matrix of clear glassy quartz, large areas of which as much as 4 mm. in diameter extinguish simultaneously. These areas are sections of grains which inclose the other minerals poikilitically. Without the analyzer the inclusions appear to be surrounded by glass. In some cases the feldspar laths up to 0.3 in length are entirely enclosed by the

quartz, and in other cases the quartz fills angular space between different crystals. (See Plate V.) The quartz contains liquid inclusions with gas bubbles, and some of the cavities are beautiful negative crystals. The fact that the quartz forms so small a part of the total mass of the rock makes this very peculiar structure appear all the more striking.

The mineral composition is given below.

Quartz	8.0%
Potash-feldspar	7.7
Plagioclase	40.3
Hornblende	34.0
Biotite	9.0
Titanite	0.7
Apatite	0.2
Magnetite	0.1
Total	100.0%

In chemical and mineral composition this rock resembles spessartite, but the structure is not like that of any spessartite that has been described. The analyses of three spessartites given by Washington will be found below, and a partial analysis of this lamprophyr made by J. M. Lindgren of the University of Illinois.

	(a)	(b)	(c)	(d)
SiO_2	50.38	53.96	50.44	55.32
TiO_2	0.59	0.60	0.72	
Al_2O_3	15.68	15.90	17.03	
Fe_2O_3	1.49	1.58	1.50	
FeO	5.65	5.56	11.02	
MnO	0.11		0.18	
MgO	9.48	7.63	5.01	5.95
CaO	7.21	6.31	8.28	6.99
Na_2O	2.86	2.99	3.02	4.39
K_2O	3.48	2.07	2.53	2.37
H_2O	2.82	3.46	0.32	
P_2O_5	tr.			

(a) Spessartite, Oberlichtenau Lauitz.

(b) Spessartite, Piz Avat Graubunden, Switzerland.

(c) Spessartite, Hutberg, Nurode, Silesia.

(d) Lamprophyr on Snowbank Lake, Minnesota.

Washington, H. S., "Chemical Analyses of Igneous Rocks," U. S. Geol. Surv. Prof. Paper No. 99, pp. 503, 505, 859, Washington 1917.

VI. ORIGIN OF ROCK STRUCTURES IN THE SNOWBANK LAKE INTRUSIVES.

Factors Controlling Crystallization

In the Snowbank syenite the feldspar and pyroxenes both indicate a marked progressive concentration of soda atoms. In the case of the feldspar this is shown by the increase in the proportion of the albite molecule present in the plagioclase, and in the pyroxene by the increase in the proportion of the acmite molecule crystallizing as an isomorphous mixture with the diopside. After the sodium had reached such a concentration that aegerite-augite was produced, new centers of crystallization were established and the iron-soda pyroxene was no longer added to the diopside.

The evidences that the greater part of the hornblende was derived from the diopside have been presented in the discussion of the latter mineral. Part of the hornblende occurs as idiomorphic zoned and twinned crystals entirely surrounded by unaltered feldspar, and part of it forms zones around diopside without any alteration of the latter. This makes it seem probable that part of the hornblende crystallized directly from the magma, and in that case the partial alteration of the diopside to hornblende must have taken place during solidification. That is, its formation was only one stage in the crystallization of the magma, and not a later episode resulting from metamorphism. Thus it is evident that following the crystallization of the pyroxene there occurred a radical change of conditions. Biotite separated and part of the diopside already formed was changed to hornblende, after which original hornblende was produced.

The cause of this fundamental change is explained by the concentration of water and mineralizing gases in the still liquid portions of the magma.

Evidence has been presented (p. 29) which shows that part of the epidote at least had a pneumatolytic origin, and this supports the view that mineralizing waters and gases were present during part of the history of the rock. N. L. Bowen says in his paper on "Later Stages of the Evolution of the Igneous Rocks," "The formation

Bowen, N. L., Supp. Jour. Geol. Vol. XXIII., pp. 41, 1915.

of hornblende and still more of the micas with their essential content of water and often of fluorine is the result of an increasing concentration of volatile constituents." This process would explain the alteration of diopside to hornblende, the later crystallization of hornblende itself, and the production of biotite. The pyroxenes tend to alter to amphiboles in the presence of water under deep-seated conditions and water is known to be essential for the formation of amphiboles from a magma. Water is also an essential part of the micas which form only in its presence. It thus seems probable that there were two distinct stages in the crystallization of the Snowbank syenite. During the first stage diopside formed and possibly part of the more basic altered feldspar. During crystallization water was being concentrated, and when the concentration had passed a certain critical point, the diopside already formed was altered to hornblende, some original hornblende formed and was added to old crystals derived from diopside, and a small amount of it produced new crystals. Biotite formed at about the same time and under similar conditions.

The relationship of the feldspar to this change of conditions is not quite clear. The phenocrysts of feldspar probably formed previous to this change and the very acid feldspar subsequent to it. The interior portions of the earlier, more basic feldspar contain remarkably large clear cut plates of colorless mica. This nucleus is surrounded by more acid feldspar that shows no evidence of ordinary weathering. These relations may be explained by the alteration of the early feldspar in the presence of water previous to the final crystalization of feldspar. There was probably some resorption of the feldspar first formed, for the more basic interiors of the grains normally show a rounded outline.

Folding.

The entire region around the lake was folded during the orogenic movements near the close of Lower Huronian time, but the intrusion of the syenite resulted in even more marked folding in parts of the area. On the east side of Snowbank Lake the Ogishki Conglomerate in immediate contact with the syenite is very intricately and closely folded, and no uniformity in the direction of the folds could be observed. The distance from crest to crest varies from a few inches up to several rods.

Crushing.

The Snowbank syenite shows evidence of crushing at several places, especially on Boot Island. A few rods southeast of the northwestern corner of the island there occurs a phase of the syenite originally composed almost wholly of feldspar. It is now a fine-grained dark green rock breaking easily into angular fragments. Under the microscope it is seen to be composed of crushed and sliced

feldspar, with warped plates of microcline and oligoclase. (Plate III.-B.) Pale green chlorite containing a little magnetite fills the spaces between mineral fragments. Some of the dikes themselves, show local crushing with recrystallization of the feldspar. The walls of many dikes, especially the pegmatites, are crushed zones, with no evidence of crushing in the dikes themselves. This proves that crushing occurred before the end of igneous activity.

Recrystallization

Recrystallization of the feldspars has occurred in the intrusive on both sides of crushed zones and the amount of the recrystallization decreases with the distance from the center of that zone. The close connection between crushing and recrystallization, and the very local occurrence of these phenomena indicate that they are not the result of general metamorphism.

The intense local folding around the border of the syenite indicates that the rock was intruded under great pressure, and therefore local strains were probably produced within the intrusive mass itself. Residual heat and local strain in the presence of moisture are the most potent forces for the recrystallization of original minerals that are known to have been present in the syenite, since there is no evidence that it has been subjected to regional metamorphism.

Myrmekite, a vermicular intergrowth of quartz and plagioclase is common in the Snowbank Lake syenite and its associated dike rocks. It is usually a plumose mass of sodic plagioclase extending into microcline at the contact with plagioclase containing a higher proportion of the anorthite molecule. In these rocks it frequently

occurs in zones and as borders along crushed areas, indicating a genetic relationship with conditions of local strain.

Sederholm who has made a close study of vermicular intergrowths and gave the name[1] to myrmekite concludes "that the process by which myrmekite is formed is a recrystallization of an isomorphous K-Na-Ca feldspar, or of orthoclase containing lime and soda in solid solution, by which plagioclase is formed. The potash is removed and the excess of silica forms vermicular rods in plagioclase.........[2]"

1. Sederholm, J. J., Bull. Comm. de Geol. Finlande, No. 6, pp. 108, 111-114, Heslingfors 1897.
2. Sederholm, J. J., "On Syntantectic Minerals," Bull. Comm. Geol. de Finlande, No. 48, Heslingfors 1916.

He concludes "that a number of observations seem to prove beyond doubt that the myrmekite of certain Rapakivi granites and also of older pre-Cambrian rocks, has been formed before the final consolidation of all the mineral constituents of the magma in question........ The formation of the myrmekite may be either earlier, contemporaneous with or later than the mechanical crushing of the rock, depending upon the succession of the events at its metamorphism......... These processes may either belong to the waning phase of igneous activity connected with the rock in question, or to the beginning of a later period of metamorphism."

Eskola,[3] after a study of the Pernio microcline granite of the

3. Eskola, Pentti, "On the Petrography of Orijarvi Region in Southwestern Finland," Bull. Comm. Geol. de Finlande, No. 40, pp. 27-28, Heslingfors 1914.

Orijarvi region of Finland says, "It seems probable that the myrmekite in part may have originated during the process of consolidation. In any case, the presence of the myrmekite cannot be regarded as a

sign of regional metamorphism." "Thus it seems that in the already partly crystallized magma fluctuations took place, caused by stress acting in the same direction as that which folded the supercrustal rocks in the leptite belt."

VII. RELATIONSHIPS AND AGE OF THE SNOWBANK LAKE INTRUSIVES.

The Syenite.

Some of the former workers have suggested that the Snowbank syenite, or granite, as it has often been called, is of two distinct

Elftman, A. H., 22nd Ann. Rep. Minn. Geol. and Nat. Hist. Surv., p. 155, St. Paul 1893.

ages. Others have divided the mass into hornblende and augite granites, but have held the two phases to be of essentially the same age.

Grant, U. S., Final Report Minn. Geol. and Nat. Hist. Surv., Vol. IV., p. 420, St. Paul 1898.
Winchell, H. V., 24th Ann. Rep. Minn. Geol. and Nat. Hist. Surv., pp. 59-66, Minneapolis 1899.
Clements, J. Morgan, "Vermilion Iron Bearing District of Minnesota," U. S. Geol. Surv. Mono. No. 45, p. 362, Washington 1903.

There had been an over emphasis of the fact that parts of the syenite contain hornblende and other portions contain augite. As a matter of fact the hornblende nearly always shows that it was derived from diopside, and usually they occur together. Nor is the color a reliable criterion by which to separate the syenite into parts, since varieties of different colors are not essentially different in any other respect. The most fundamental difference that has been found in the syenite is the large development of microcline in one phase of the rock and its absence except in microperthite from others. It is doubtful however if even here we have to deal with an essential difference.

The border phase characterized by alkalic feldspar may be somewhat later than the microcline-oligoclase phase. Dikes of the albite syenite cut the syenite on Boot Island, but the features of

these dikes indicate that the second intrusion took place before the predominant syenite had entirely cooled. In nearly all properties the materials of the two intrusions are very closely related, and the conclusion seems obvious that there is no marked difference in their ages.

The Dike Rocks.

The various dikes connected with the Snowbank syenite form a remarkably perfect complementary system. Some are identical with one or the other phase of the syenite in all essential characteristics and nearly all show marked consanguinity with it. The lamprophyrs are the only rocks that do not give clear evidence of their close relationship to the syenite. All other types of dikes are rich in soda, have the same remarkable zoned and intergrown feldspar and the same accessory minerals. The table given on Plate IX. will serve to bring out these peculiarities.

The lamprophyr dikes cut both the Ogishki Conglomerate, and the Knife Lake Slates of the Lower Huronian in this region just as the syenite does. The Upper Huronian does not occur in this part of the region, but elsewhere it has been observed that the dikes do not cut Upper Huronian. Thus there is structural evidence to show that the age of the lamprophyrs cannot be very different from that of the Snowbank syenite which likewise intrudes Lower Huronian but not the upper series. The lamprophyr dike rocks contain sodic feldspar intergrown with potassic feldspar as in the syenite and other dike rocks. The diopside is the same green variety intermediate between normal diopside and aegerite-augite. The lamprophyrs are very high in femic minerals, but not more so than some other parts of the Snow

bank intrusive series. There appear to be all transitions from the extremely silicic dikes to those of lamprophyre. These things seem to indicate very strongly that the lamprophyr dikes are a part of the Snowbank intrusive system.

The relationships of the porphyries on the west side of the lake to the Snowbank syenite are not yet clear. It seems most probable that they are a part of the Snowbank intrusives, but even though they may finally be correlated with the Giants Range granite there can be no doubt as to their close consanguinity with the syenite.

Consanguinity of the Syenite and the Dike Rocks.

The close genetic relationship of the various phases of the syenite and dike rocks in the neighborhood of Snowbank Lake, and the similarity existing between them and the granites of Cacaquabic and the Giants Range is well brought out by a tabulation of their characteristic components. This has been done and the results shown below. It will be at once noted that if quartz is excluded from consideration all the rocks in question contain the same components except that microcline in individual crystals and aegerite-augite are present in a few and not in others. It has been shown that one component of the intergrown feldspar which is present in all these rocks is microcline, and the green color of the diopside shows that even when aegerite-augite is not present the crystallizing magma was rich in acmite molecules. Thus the slight variations in mineral composition are probably due to differences in the processes of crystallization, since some of the magmas contain as much K_2O and Na_2O as those that produced those minerals.

Age.

The manner in which the Snowbank syenite cuts the Ogishki Conglomerate and Knife Lake Slates has been described. (See p. 83.) The folding, contact metamorphism, and the injection of syenite material into the slates and conglomerates (See Plate VIII.-B) make it clear that the syenite is younger than these sediments. Since both these formations are Lower Huronian in age we know that the syenite was intruded near the close of Lower Huronian or after Lower Huronian time. There is only one small exposure of Upper Huronian in the region occurring on the south side of Disappointment Lake. This exposure does not enable us to determine the relationship of the syenite to the Upper Huronian. However, no acid intrusions or dikes have been observed to cut the Upper Huronian in the Vermilion region. On the other hand, the syenite is metamorphosed by the Duluth gabbro which is of Keweenawan age. We can therefore say that the syenite is younger than the Lower Huronian sediments and older than the Duluth gabbro.

The whole region of which the syenite is a part was intensely folded and underwent regional metamorphism between the time of the Lower and Upper Huronian. The close of the Lower Huronian is believed to have been a period of mountain-making, and it seems reasonable to assume that this was the time when the intrusion of the Snowbank syenite took place.

Van Hise and Leith, "Geology of the Lake Superior Region," U. S. Geol. Surv. Mono., No. 52, p. 129, Washington 1911.

The Giants Range granite and the Cacaquabic granite bear exactly the same relations as does the Snowbank Lake syenite to the Lower Huronian formations, the Upper Huronian formations and the Duluth

gabbro, and they are therefore believed to be of approximately the same age as the Snowbank syenite.

VIII. CONTACT METAMORPHISM

By the Syenite

The Snowbank Lake syenite is in contact with Ogishki Conglomerate on both the east and west sides of the lake and with the Knife Lake Slates on the north side. Noticeable contact metamorphism seems to be confined largely to the conglomerate on the immediate border of the syenite on the east side of the lake. (See Plate VIII.-A and B.)

All the rocks older than the syenite were subjected to profound regional metamorphism at the time the Lower Huronian was closely folded. The syenite was intruded under great pressure, resulting in close local folding in part of the area, and the injection of syenite material far into the sediments. (See Plate VIII.-B.) On the eastern side of Snowbank Lake the folding in the sediments is so close that in some specimens the distance from crest to crest of the folds is less than an inch. In the greatest number of cases there is no symmetry to the folding and the sediments are twisted and distorted in all manner of shapes. The presence of boulders of granite in the conglomerate around which the injected material often flowed has increased the complexity of the structure.

Porphyries were formed on the western side of the lake and the sediments in contact with them show little evidence of contact metamorphism and no injection of the intrusive magma into the wall rocks Either the cover was thicker above the intrusive magma on the eastern side than on the western side of the lake, or erosion has proceeded farther on the eastern side, exposing syenite formed at a greater depth. In either case, conditions would be favorable for a

greater concentration of mineralizing gases and a longer retention of heat in the rocks exposed to view on the eastern side of the lake, thus favoring contact metamorphism.

The sediments in contact with the Duluth gabbro show evidences of contact metamorphism one-half mile or more from the border of the gabbro, but there was no marked folding of the sediments or injection of gabbro into them. This indicates that the contact metamorphism produced by the gabbro was more widespread than that by the syenite. On the other hand the gabbro caused very little dynamic metamorphism on its wall rocks, while dynamic metamorphism of the syenite was locally very intense. In parts of the area the metamorphic effect of the gabbro was added to that of the syenite, and it is difficult to determine definitely the part played individually by the various forces in the production of the present rocks.

INJECTION GNEISSES. Close to the syenite the graywacke that forms the matrix between the pebbles of the Ogishki Conglomerate was thoroughly impregnated by the syenite magma forming impregnation and injection gneisses. (See Plate VIII.-B.) These gneisses are medium-grained, being finer grained than the syenite itself. The rock is composed of dark hornblende and biotite, pale pink feldspars, and a small amount of quartz, and is so thoroughly recrystallized that much of the hornblende is idiomorphic. The feldspars are derived largely from the injected syenite and their proportion decreases as distance from the syenite increases. The hornblende exceeds the biotite in quantity, and potash feldspar exceeds sodic feldspar. The latter has a lower index of refraction than quartz, and an angle of extinction of about 5° at right angles to the plane (010), indica-

ing a composition near $Ab_{85}An_{15}$. The hornblende is rather light colored, its pleochroism varying from pale yellow to light bluish green.

The mineral composition of a typical specimen is given below. Its feldspar is nearly fresh, containing a little colorless mica. Intergrowths of potassic and sodic feldspars, similar to those in the syenite, are present and a few crystals of feldspar are idiomorphic in relation to the quartz.

Potassic feldspar	46.0%
Oligoclase	31.0
Hornblende	20.0
Biotite	2.0
Magnetite	0.7
Titanite	0.3
Total	100.0%

HORNBLENDE-BIOTITE SCHIST. Beyond the zone of injection, the graywacke enclosing the boulders of the Ogishki Conglomerate has become a fine-grained dark gray hornblende-biotite schist. The feldspar composing it is white and a smaller proportion is potassic than in the injection gneisses. The plagioclase is near albite-oligoclase with an angle of extinction of 6° at right angles to the plane (010). The quartz is unusually limpid, and occurs in roughly rounded but interlocking grains. The hornblende and biotite do not differ from that already described. The metamorphic effects have resulted in a recrystallization of the feldspars and the production of hornblende and biotite plates of megoscopic size giving rise to a very distinct schistosity which is lacking in the original graywacke.

The mineral composition of a typical specimen of this type of rock is as follows:

Quartz	32.0%
Oligoclase	35.0
Orthoclase	10.0
Biotite	14.0
Hornblende	9.0
Total	100.0%

Another specimen collected in the region between Round and Snowbank lakes is a fine-grained, nearly black, slaty schist, from the Knife Lake Slates, lying conformably above the Ogishki Conglomerate. A microscopic examination shows the rock to be composed of rounded grains of quartz and feldspar about 0.05 mm. in diameter and hypidiomorphic hornblende in the following proportions:

Quartz	28.0%
Feldspar	32.0
Biotite	7.0
Hornblende	30.0
Magnetite	3.0
Total	100.0%

On the southwest side of Round Lake, the Knife Lake Slate is composed of over 40 per cent hornblende, and 20 per cent reddish brown biotite, but otherwise is similar to the slaty schist just described.

All these rocks show the effect of metamorphism by the syenite in the increased coarseness of grain and their greater schistosity as compared with the normal slates.

BLASTOPORPHYRITIC SCHISTS. On the east side of Snowbank Lake near the western side of sec. 32, and in the region between Round and Snowbank lakes, there occur gray blastoporphyritic schists. Some of these have a distinct schistosity and others are quite massive. These rocks are characterized by prominent porphyroblasts of quartz and white feldspar exceeding quartz in proportion. In the hand specimen the quartz appears to be slightly elongated in the

direction of schistosity. The feldspar is hypidiomorphic and shows no evidence of crushing. In some specimens there is no regularity in the orientation of the mineral grains, but in others their greatest length is parallel to the schistosity. Under the microscope the quartz porphyroblasts are seen to be composed of one or several grains with the lines of liquid inclusions typical of quartz of igneous origin running across the boundary between them. This seems to indicate that the quartz has been slightly crushed, but that there has been little recrystallization since it was formed.

The feldspar porphyroblasts often have a serrate outline due to the recrystallization of the groundmass on the border, but the general outline is hypidiomorphic. The feldspar of the porphyroblasts is much more altered than the feldspar of the groundmass, probably due to the more complete recrystallization of the latter. In a few cases fresh grains of feldspar have recrystallized within the porphyroblasts, showing that the porphyroblasts are older than the fresh feldspar. Both potassic and sodic feldspar are present.

The groundmass is similar to the injection gneisses previously described and intergrowths of sodic and potassic feldspar similar to those in the syenite are to be observed. The porphyroblastic schists are not in immediate contact with the syenite, however, and the amount of injected material is small. The feldspar of the groundmass is predominantly acid plagioclase with an angle of extinction of about 6°. The hornblende which forms about 10 per cent of the rock, is the common green variety. Biotite constitutes only about 3 per cent of the rock and is greenish brown. There are notable amounts of apatite and titanite together with a little epi-

dote. Large areas in the thin section are crowded with grains of colorless diopside derived from the hornblende. Many of the grains are entirely altered to diopside, but others are diopside on the outer border and hornblende in the interior. The diopside is fresher and lighter colored than that in the syenite. The angle of extinction is about 40°.

The blastoporphyritic schists are parallel bands, 10 to 20 feet wide, between normal Ogishki Conglomerate containing numerous granite boulders. There can be no doubt that the schists are only a phase of the Conglomerate similar to the coarse graywacke bands that are common throughout all the conglomerate of the region. The minerals which form the porphyroblasts are undoubtedly feldspar and quartz fragments of the same granite that furnished the boulders occurring in the normal conglomerate. Thus the porphyroblastic schists have the same origin as the recomposed granite of the same age that occurs on Lake Saganaga, 25 miles northeast. In this locality the Saganaga granite has broken down into individual grains of feldspar and quartz which have been recemented to a quartz feldspar rock very similar to the granite from which it was derived.

Clements, J. Morgan, "Vermilion Iron Bearing District of Minnesota," U. S. Geol. Surv. Mono. No. 45, pp. 169-173, Washington 1903.
Grant, U. S., 20th Ann. Rep. Minn. Geol. and Nat. Hist. Surv., pp. 88-92, Minneapolis 1891.

Some of the specimens collected on the east side of Snowbank Lake are massive and very similar to the recomposed granite on Lake Saganaga. It is not strange that the larger fragments of feldspar and quartz should remain unaltered when the granite boulders within a few feet of them are unchanged, as is the case on the east side of

Snowbank Lake.

Of the Syenite by the Duluth Gabbro

DESCRIPTION. The Duluth gabbro forms a range of hills on the south of the syenite area standing about a hundred feet above it, since the syenite is closer jointed than the gabbro and was more easily removed by glacial action. In most cases the contact between the gabbro and the syenite is occupied by depressions or swamps. In a few places, however, a rock is exposed in rounded knobs that apparently resulted from the metamorphism of the syenite by the gabbro. The best exposures of this rock are found about a quarter of a mile south of the southern shore of Round Lake and about 10 feet from the border of the gabbro.

On the weathered surface the metamorphosed syenite resembles the weathered surface of the normal syenite more than that of the gabbro. A freshly fractured specimen has the color of gabbro and might at first sight be taken for a granulated gabbro. Biotite and feldspar are the only minerals recognizable in the hand specimen. The feldspar is gray and the rock itself is dark gray, almost black. None of the feldspar crystals are euhedral as they are in the gabbro.

MINERAL COMPOSITION. Plagioclase forms nearly 75 per cent of the rock and is the only feldspar present. It is very fresh and glassy in appearance, containing no mica flakes as is often the case in the normal syenite. The only impurity is a small amount of iron oxide. The plagioclase has extremely minute albite twinning lamellae. The angle of extinction perpendicular to the plane (010) is 3°30' and this taken together with the fact that the index of refraction is slightly higher than that of balsam indicates that the

feldspar is oligoclase of about the composition $Ab_{78}An_{22}$. The Schuster method was applied to small grains giving an angle of extinction of 7° on the plane (010). This indicates the same feldspar composition as does the other method. The plagioclase is slightly more calcic than that in the unaltered syenite as the latter is usually above $Ab_{80}An_{20}$ in the albite molecule, while that in the normal gabbro has a composition of about $Ab_{40}An_{60}$. The plagioclase of the metamorphosed syenite is only slightly more calcic than the plagioclase of the normal syenite, but very much more acid than that of the gabbro.

Biotite is the most abundant femic mineral and is similar to that in the gabbro. It has a pale chestnut-brown color with a redder tint than the biotite in the syenite. The optical angle is very close to 0° and no rutile is present. The diopside is colorless or has a faint violet pleochroism and does not resemble the pale green diopside of the syenite but is like that of the gabbro. The angle of extinction is 39° and crystals are subhedral, often occurring as rounded grains. A very small amount of pale brown amphibole with an angle of extinction of 16° is present in the rock. This is probably near barkevikite in composition. Much of the biotite and diopside exhibits a complex vermicular intergrowth similar to, but coarser than, that seen in myrmekite. Olivine occurs as single crystals entirely surrounded by acid plagioclase, as crystal aggregates, and as an intergrowth with the other femic minerals. Most commonly it is intergrown with diopside. The femic minerals sometimes form irregular aggregates where minute grains of magnetite, biotite, and plagioclase are disseminated in large diopside masses

that have uniform extinction. There seems to be a definite order in the formation of the femic minerals. The first mineral to crystallize was either magnetite or olivine, followed by diopside and that by biotite. The complex intergrowths of biotite and diopside show, however, that the period of crystallization of diopside and biotite overlapped.

The minerals of the rock are only slightly altered, olivine showing the greatest change. A small amount of common pale green fibrous serpentine has formed from the olivine but dark brown masses of iddingsite are far more common. The latter mineral has entirely replaced some olivine crystals, but in most cases the iddingsite has begun to form along the cleavage cracks just as serpentine commonly forms. Some of the biotite has partially altered to deep green chlorite, but it still retains its high index of refraction and apparent uniaxial character.

The mineral composition of the rock is as follows:

Oligoclase	74.2%
Biotite	7.5
Diopside	8.4
Olivine	4.5
Magnetite	2.1
Serpentine (Iddingsite)	0.7
Barkevikite	2.3
Chlorite	0.3
Total	100.0%

CHEMICAL COMPOSITION. A partial analysis of the metamorphosed syenite (I.) was made by J. A. Lindgren. An analysis of the microcline-oligoclase syenite (II.) and of a specimen of the albite border phase (III.) are given for comparison.

	I.	II.	III.
SiO_2	58.12%	60.70%	58.77%
MgO	5.25	1.56	3.18
CaO	5.33	4.89	5.04
Na_2O	5.89	4.63	6.05
K_2O	2.10	6.74	3.46
Total	76.69%	78.52%	78.50%

The color and angle of extinction of the diopside indicate that it has nearly the theoretical composition of this mineral, so we can assume that it contains about 21 per cent CaO. Since the amount of calcium would be very low in the other femic minerals it may be neglected without introducing a large error in the calculation of the composition of the feldspars present. Deduction must be made for the K_2O in the biotite, but the small amount in the other femic minerals may be neglected. The Na_2O in minerals other than feldspar must be so small that no deduction is made for it. The alkalies and lime free to form feldspars, and the various feldspars theoretically resulting therefrom, are:

CaO	3.57%
Na_2O	5.89
K_2O	1.26
An	17.76
Ab	49.92
Or	7.39
Total	75.07%

The microscope shows that but one feldspar is present in the metamorphosed syenite, so its composition expressed in parts in 100 would be Ab. 66.5, Or. 9.8, An. 23, 7, or approximately $(Ab., Or.)_{77}$ An_{23}. The optical properties indicated a feldspar of the composition $Ab_{77}An_{23}$. The difference between the results of observation and calculation may be partially explained by the fact that a portion of the sodium has been replaced by potassium; but more probably the

alkalies in the femic minerals were not present in quite the proportions assumed.

ORIGIN. It is clear from both the microscopic study and the partial analysis that there has been a transfer of material from the gabbro to the syenite. The microscope shows that there has been an addition of important amounts of iron in the form of magnetite. The diopside and olivine indicate that there has been a transfer of magnesium. Olivine could form in so acid a rock only by the direct transfer of material from a basic intrusive magma. The metamorphosed syenite was derived from a phase of the Snowbank syenite containing very acid feldspars. It was probably low in femic minerals, as the metamorphosed syenite 80 feet farther from the gabbro contains but 5 per cent of such minerals. A comparison of analyses shows that there is a greater proportion of magnesia present in the metamorphosed syenite than in the unmetamorphosed syenite and that the proportion of calcium has increased.

The metamorphic effects of the gabbro on the syenite can be summed up as follows: There was a complete recrystallization of the syenite with the production of extremely limpid feldspar of but one variety. This is a potash albite of the approximate composition $Ab_{67}Or_{10}An_{23}$, which is slightly more calcic than the feldspar in the original rock, due probably to the transfer of a small amount of calcium from the gabbro. There was the production of colorless diopside similar to that of the gabbro by transfer of material from the gabbro. Olivine was produced in a sodic rock by the transfer of magnesium and iron. Important amounts of magnetite were produced, largely as the result of a transfer of iron.

The degree of metamorphism and the proportion of introduced femic minerals decrease rapidly as distance from the gabbro increases.

At a distance of 90 feet from the gabbro the syenite has been changed from a pink to a gray color somewhat lighter than the one just described. Most of the feldspar grains are light gray, but a few retain their original pink tint. The feldspar is unstriated plagioclase but is slightly recrystallized. It contains a larger proportion of alteration products than the feldspar in the metamorphosed rock closer to the gabbro. The principal femic mineral is pale violet colored diopside similar to that found in the gabbro. A very small amount of biotite is present but the total femic minerals do not amount to over 5 per cent of the total.

The rapid decrease in the proportion of femic minerals shows that the solutions from the gabbro did not transport material far into the contiguous syenite. This rock shows no effect of contact metamorphism beyond the narrow margin where chemical solutions were effective. The sedimentary rocks, on the other hand, are metamorphosed as much as one-fourth of a mile from the gabbro contact.

A specimen taken at the head of the most southern bay of Round Lake shows the syenite in direct contact with the gabbro, and it was possible to secure a section across the contact. The feldspar of the syenite still retains its pink color but under the microscope shows some recrystallization. A few very large grains of magnetite have formed beyond the contact, and some pale violet diopside is present. Most of the diopside gives evidence by its slightly green color that it is original to the syenite. On the gabbro side of

the contact there is a zone about an inch wide where there has been a concentration of femic minerals. The alteration of the syenite was slight in this case.

IX. COMPARISON BETWEEN THE SYENITE AND THE GRANITES OF THE VERMILION RANGE

CACAQUABIC GRANITE. The marked similarity between the Snowbank Lake syenite and the Cacaquabic granite has been noted by former

Winchell, N. H., Final Rep. Minn. Geol. and Nat. Hist. Surv., Vol. IV., pp. 287-289, St. Paul 1899.

workers. Both are sodic rocks low in quartz, with hornblende and augite facies. In his excellent study of the Cacaquabic granite, U. S. Grant[1] gives an analysis of the feldspar and believes it to be

1. Grant, U. S., 21st Ann. Rep. Minn. Geol. and Nat. Hist. Surv., pp. 44, Minneapolis, 1892.

anorthoclase of the approximate composition $Or_5Ab_{14}An_1$. He shows that the rock is rich in soda, low in quartz, and that it contains large amounts of aegerite-augite. Mr. L. E. Kennedy[2] gives an analysis of the granite and in an exhaustive study of the feldspars shows them to be intergrown albite and soda microcline.

2. Kennedy, L. E., Unpublished thesis, University of Illinois, 1918.

GIANTS RANGE GRANITE. Thin sections of the Giants Range granite from the Kawishwi River region were loaned for study by the Minnesota Geological Survey, but the rocks from which they were made were greatly weathered and it was difficult to determine very much with their help. C. K. Leith loaned hand specimens and sections of the Giants Range granite from various places farther east, and the following brief study was made largely from this material.

The Giants Range granite is a pinkish white to red rock with medium to coarse grain, and variable amounts of pyroxene and hornblende. The feldspars are microcline and oligoclase in nearly equal amounts. Microcline often forms phenocrysts, and its relations to

quartz and other minerals indicate that in all cases it is the result of an original crystallization from the magma. It contains lens-like inclusions of another feldspar similar to that in the Snowbank syenite. The plagioclase has an angle of extinction of between 5^{o} and 6^{o}, and its index of refraction is higher than that of quartz; consequently it must be an oligoclase of about the composition $Ab_{75}An_{25}$. The hornblende is dark green to olive-green in color and is the result of alteration of pyroxenes. In some cases it forms as much as 30 per cent of the rock mass. The pyroxene is light green and its color and high angle of extinction show it to be intermediate in composition between normal diopside and aegerite-augite. There are also present large amounts of titanite and apatite. The alteration products are colorless mica formed from the feldspars and epidote from the femic minerals.

The above description shows that the Giants Range granite has much in common with the Snowbank syenite. The analysis of the Giants Range quoted below was made from a more salic phase than is represented by the specimens studied.

SAGANAGA GRANITE. The Saganaga granite is of Archean age. It is a sodic rock with very large quartz crystals and contains hornblende or biotite. Hornblende predominates over biotite, and the feldspars seem to be plagioclase near oligoclase-andesine, with smaller amounts of orthoclase. The granite is very much altered, and material was not at hand to make a satisfactory study of its petrographic character. The analysis given in the table shows that it has a chemical similarity to the Snowbank syenite and the Cacaquabic granite, but no conclusion as to relationship can be made.

Chemical and Mineralogical Similarities

Analyses of the various granites and porphyries of the Vermilion range show their close chemical relationships.

ANALYSES OF CERTAIN ACID INTRUSIVES OF THE VERMILION RANGE.

	I.	II.	III.	IV.	V.	VI.
SiO_2	59.63%	65.16%	66.84%	67.42%	69.70%	69.34%
Al_2O_3	16.11	15.88	18.22	15.88	18.72	17.25
Fe_2O_3	4.87	1.20	2.27	1.37	0.65	2.46
FeO	0.87	1.18	0.20	1.14	0.79	.....
MgO	3.16	1.75	0.81	1.43	0.45	1.18
CaO	5.02	2.40	3.31	3.49	2.25	3.43
Na_2O	5.83	5.84	5.14	6.42	5.01	4.33
K_2O	3.45	5.60	2.80	2.65	1.68	0.71
H_2O	0.78	0.66	0.46	0.05	0.71	1.17
TiO_2	0.62	0.24	.....	.....	.....	.....
P_2O_5	0.58	0.07	Tr.	0.07	.....	.....
MnO	.....	.....	.....	Tr.	.....	.....
	100.65%	99.98%	100.05%	99.92%	99.96%	99.87%

I. Snowbank syenite. By J. M. Lindgren of the University of Illinois.
II. Cacaquabic granite made for Mr. L. E. Kennedy by the same analyst. Unpublished thesis, University of Illinois, 1918.
III. Cacaquabic granite. By U. S. Grant, Minn. Geol. and Nat. Hist. Surv. Vol. 21, p. 41, 1892.
IV. Cacaquabic porphyry. By U. S. Grant, Minn. Geol. and Nat. Hist. Surv. Vol. 21, p. 43, 1892.
V. Quartz porphyry of the Giants Range granite on the Kawishiwi River. By U. S. Grant, Minn. Geol. and Nat. Hist. Surv. Vol. 21, p. 41, 1892.
VI. Laurentian Saganaga granite. Quoted by U. S. Grant, Minn. Geol. and Nat. Hist. Surv. Vol. 21, p. 41, 1892.

The norms of three important Huronian intrusives are indicated below.

I. The norm of the Snowbank Lake syenite.

II. The norm of the Cacaquabic granite calculated from Lindgren's analysis by Mr. Kennedy.[1]

1. Kennedy, L. E., Unpublished thesis, University of Illinois, p. 49, 1918.

III. The norm of the quartz porphyry of the Giants Range, calculated from analysis V.

		I.		II.		III.
Quartz		1.86		4.08		28.14
Orthoclase		20.02		33.36		10.10
Albite		49.26		49.25		42.44
Anorthite		7.78		0.56		11.12
Corundum		0.00		0.00		4.49
Salic minerals	78.92		87.25		96.20	
Diopside		10.37		8.99		0.00
Hypersthene		3.00		0.83		2.02
Magnetite		0.93		1.86		0.93
Hematite		4.16		0.00		0.00
Ilminite		1.22		0.46		0.00
Titanite		0.00		0.00		0.00
Apatite		1.34		0.00		0.00
Femic minerals	21.02		12.14		2.95	
Salic minerals	78.92		87.25		96.20	
H_2O	0.78		0.66		0.71	
Total	100.72		100.05		99.86	

The following table gives the modes of the Snowbank Lake syenite and the Cacaquabic granite.

Snowbank syenite.			Cacaquabic granite.	
Albite-oligoclase	48.6	86.7	Quartz	4.41
Microcline	20.6		Feldspar	83.39
Oligoclase	17.5			
Hornblende	6.5		Katoforite	3.01
Diopside	2.6		Aegerite-augite	7.10
Titanite	1.1		Titanite	1.19
Magnetite	1.2		Magnetite	0.73
Biotite	0.5			
Apatite	1.4		Apatite	0.17
Total	100.00			100.00

The close chemical and mineral similarity of the Cacaquabic granite and the Snowbank syenite is evident from the foregoing. Both rocks are low in silica and high in soda. Both contain large amounts of soda plagioclase intergrown with soda microcline in the

same peculiar manner. Both are characterized by aegerite-augite phases and by hornblende derived from pyroxene. Titanite occurs in unusual amounts in the two rocks.

The similarity between the Snowbank Lake syenite and the Giants Range granite is not so apparent. They are both strongly sodic, but the latter is much more silicic than the former.

X. SUMMARY AND CONCLUSIONS

The conclusions reached in the foregoing paper may be summarized as follows:

1. The soda rich Snowbank Lake syenite is characterized by lens-like intergrowths of albite and microcline.

2. This perthitically intergrown albite and microcline was originally a calcium-sodium-potassium plagioclase near albite in composition. During the final cooling of the magma changed conditions rendered the potassium feldspar insoluble in the calcium-sodium feldspar and lenses of microcline separated from the solid solution of the two feldspars.

3. Zonal structure in the plagioclase indicates a progressive concentration in the sodium content of the magma, and this is confirmed by the increase in the acmite molecule in the last pyroxene to form.

4. A portion of the epidote is the result of pneumatolytic action.

5. The diorite of Boot Island and the granite between Snowbank and Disappointment lakes are true differentiates.

6. During the crystallization of the Snowbank Lake syenite there was a concentration of water and mineralizing gases. This resulted in the formation of biotite, the alteration of diopside to hornblende, the production of colorless mica laths in the older and more calcic feldspars, and the production of pneumatolytic epidote.

7. The dike rocks of the Snowbank Lake region form a very complete complementary series, and show a marked chemical and mineral-

ogical consanguinity with the syenite.

8. The dike rocks belong to both the aschistic and diaschistic groups. The former group includes granites and syenites, both porphyritic and non-porphyritic. The latter group embraces pegmatites, aplites, bostonites, malchites, and lamprophyrs.

9. A portion of the dikes were intruded before the complete cooling of the syenite magma, and others after cooling, since their walls are crushed.

10. The recrystallization of feldspars and the production of myrmekite was induced by heat and pressure and occurred during the cooling of the syenite, so that in this rock myrmekite is not evidence of regional metamorphism.

11. The unmixing of solid feldspar solutions, alteration of diopside to hornblende, the production of colorless mica, epidote, myrmekite and recrystallization of feldspars was but the effect of a waning phase of igneous activity.

12. The Snowbank syenite shows close chemical and mineralogical relationship to the Cacaquabic and Giants Range granites.

13. Dynamic metamorphism of the surrounding rocks by the Snowbank syenite is more marked than the contact metamorphism. Both these effects are confined to the eastern and southern borders of the syenite, but are obscured in much of the area by the contact metamorphism produced by the Duluth gabbro, and by the regional metamorphism.

14. The blastoporphyritic schists in the neighborhood of the syenite contain quartz and feldspar derived from an older granite, and are in reality recomposed granites.

15. The syenite has been metamorphosed by the Duluth gabbro, with the introduction of magnetite, titaniferous augite and olivine. Chemical analyses show the introduction of iron, magnesium and calcium.

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Winchell, N. H., 24th Rep. Minn. Geol. and Nat. Hist. Surv., pp. 59-66, Minneapolis 1899.

Winchell, N. H., Final Rep. Minn. Geol. and Nat. Hist. Surv., Vol. IV., pp. 287-289, Minneapolis 1899.

Winchell, N. H., Final Rep. Minn. Geol. and Nat. Hist. Surv., Vol. V., p. 773, Minneapolis 1899.

APPENDIX

Biography

Place and date of birth:

Eldora, Iowa. September 20, 1880.

Education:

Eldora, Iowa, High School, 1895-1897.

Kansas State Agricultural College, 1909.

University of Illinois, 1910-1917.

Degrees:

A. B., University of Illinois, 1913.

A. M., University of Illinois, 1915.

Honors:

Sigma Xi, 1915.

Teaching experience:

Assistant in Geology at the University of Illinois, 1913-1917.

Professional experience:

Summers of 1912 and 1913. Field work with the Illinois State Geological Survey.

Summer of 1915. With Prather Mining Company, Joplin, Missouri.

Summer of 1916. Field work in Vermilion and Mesabi Iron Ranges of Minnesota.

Associate Geologist, with United States Geological Survey 1917 to the present.

1917. Study of pyrite in North Carolina and South Carolina.

1918. Stratigraphic and structural oil geology in Oklahoma.

1919. Stratigraphic and structural oil geology in Texas.

1919. Areal geology in San Juan Mountain and San Luis Valley

region of Colorado and New Mexico.

Publications:

"The Chloritic Material in the Ores of Southeastern Missouri," Trans. Illinois Acad. Sci. 1916.

With Savage, T. E., "The Age of the Iron Ore of Eastern Wisconsin," Am. Jour. Sci., 4th Ser., Vol. 41, 1916.

"Structure and Oil and Gas Resources of the Osage Reservation, Oklahoma:" Tps. 20 and 21 N., R. 12 E., Bull. 686-N, U. S. Geological Survey, Washington 1919.

"Structure and Oil and Gas Resources of the Osage Reservation, Oklahoma," Tps. 21 and 22 N., R. 11 E., Bull. 686-O, U. S. Geological Survey, Washington 1919.

With Bowen, C. F., Roundy, P. V., and Reeves, Frank, "Structure and Oil and Gas Resources of the Osage Reservation, Oklahoma," Tps. 21-23 N., Rs. 6-7 E., and Tps. 23-25 N., Rs. 3-5 E., Bull. 686-U, U. S. Geological Survey, Washington 1919.

Plate I.

A. Microperthitic intergrowth of albite and microcline. The lens-like inclusions of microcline in the albite show on the right. Crossed nicols, X 45.

B. Microperthitic intergrowth of albite and microcline. Twinning characteristic of microcline shows in the center, and small lenses of albite in microcline appear on either side of the quartz crystal (white) near the top. Crossed nicols, X 58.

PLATE I

A.

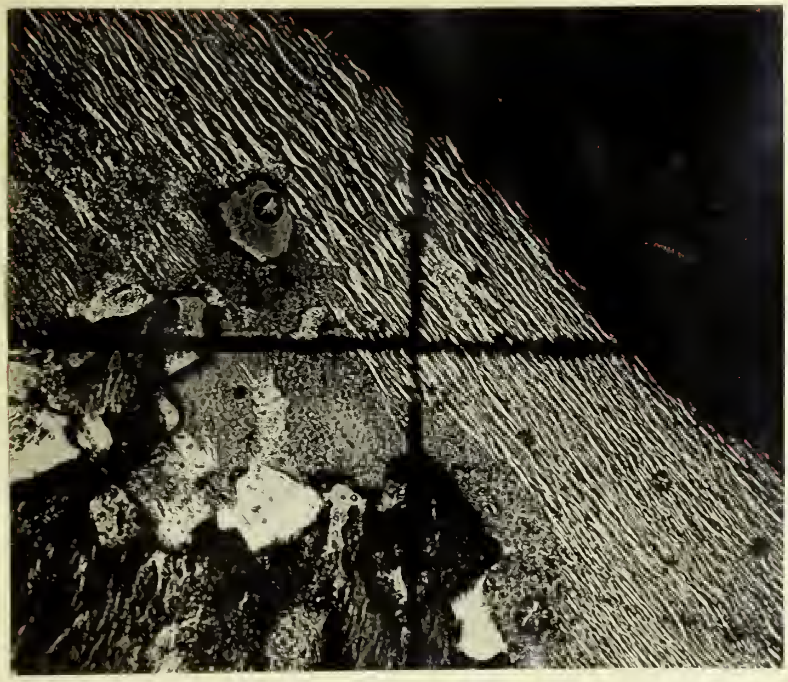
B.

Plate II.

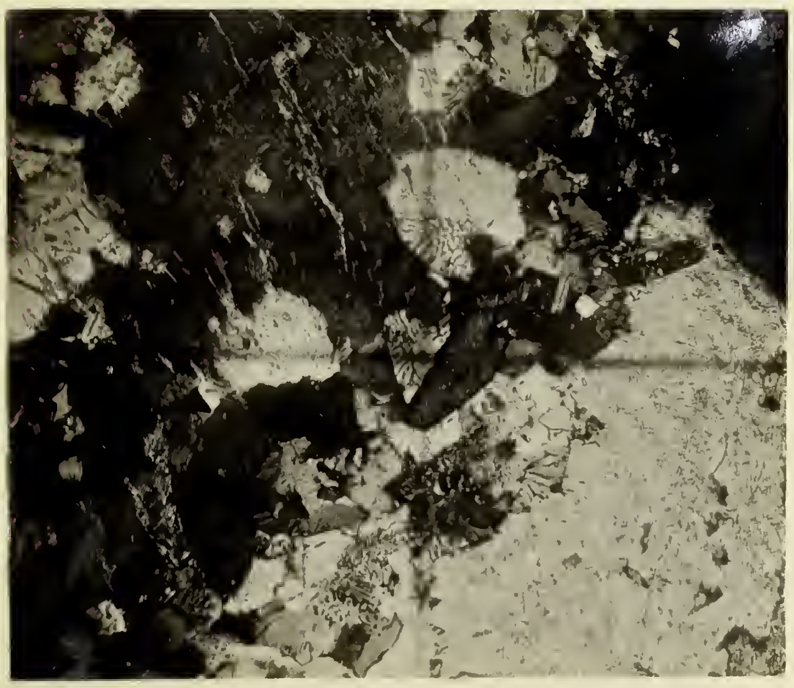
A. Microperthitic intergrowth of albite and microcline. The lens-like inclusions of microcline in albite form a border along the outer edge of a plagioclase crystal (black). Crossed nicols, X 200.

B. Zone of myrmekite accompanied by recrystallized feldspar on the border of a crushed area. The myrmekite areas are embayments in original plagioclase crystals. The small crystals associated with the myrmekite are of secondary feldspar. Crossed nicols, X 46.

PLATE II.



A.



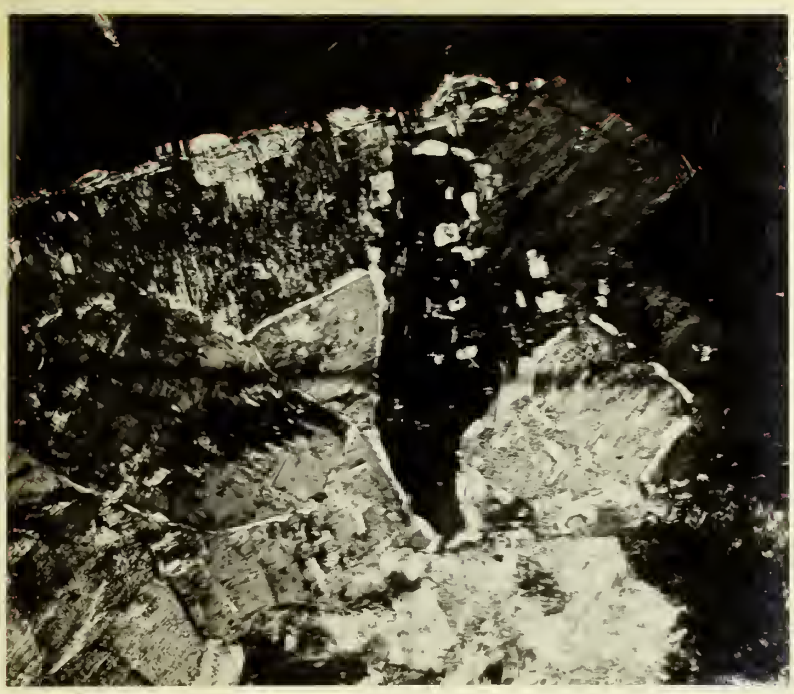
B.

Plate III.

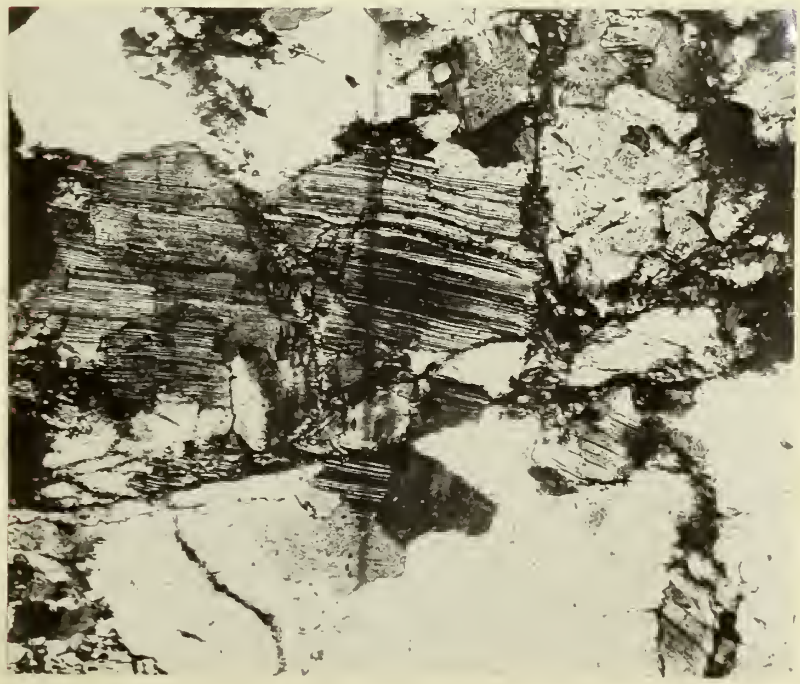
A. Idiomorphic albite without twinning lamellae. A very narrow zone of quartz (white) fills the spaces between the albite grains (gray). Crossed nicols, X 58.

B. Syenite from a crushed zone. Crushed feldspars (upper right), and plagioclase with distorted twinning lamellae (center). Crossed nicols, X 60.

PLATE III



A



B

Plate IV.

A. Idiomorphic, zoned and twinned hornblende crystal, characteristic of the aplites. The sharply defined line extending diagonally across the crystal is a twinning lamellae. The clearcut dark outer zone indicates a sudden, rather than a gradual change in the composition of the hornblende. Crossed nicols, X 50.

B. Hypidiomorphic, zoned hornblende crystal in the normal syenite. The shape and zoning indicate that the hornblende crystal shown is original and not the result of the alteration of diopside. Crossed nicols, X 53.

PLATE IV

A

B

Plate V.

Spessartite-like rock with poikilitic inclusions of plagioclase and hornblende in quartz. The white is quartz and all of that appearing in the microphotograph is part of a single crystal. The black is hornblende, and the gray with twinning lamellae is plagioclase. Crossed nicols, X 50.

PLATE V

Plate VI.

A. The region between Snowbank and Moose lakes. Canoe being carried over the portage trail between the lakes. Birch and jack pine are seen in the foreground and spruce poles killed by fire in the background.

B. Burned area between Snowbank and Round lakes. The dead spruce poles were killed by fire, and later most of them were blown down by winds, rendering travel very difficult.

Plate VI.

A.

B

Plate VII.

A. Ogishke Conglomerate on the east side of Snowbank Lake. The pebbles are predominately Archean granite, but a few are rhyolite, Ely greenstone and Soudan iron bearing formation.

B. Knife Lake Slate on the east side of Snowbank Lake. The bedding planes are clearly shown, and gentle folding has occurred on the right. The light colored bands are stringers of Snowbank Lake syenite that has penetrated along bedding planes in the slate.

Plate VII.

A

B

Plate VIII.

A. Fragments of Ely greenstone included in the Snowbank Lake syenite on the east side of Snowbank Lake. The syenite is not in contact with the greenstone at the surface, but during intrusion fragments were carried up from below.

B. Knife Lake Slate penetrated by stringers of Snowbank Lake syenite on the east side of the lake. The gray is massive slate and the light colored veins and branching stringers are syenite.

Plate VIII.

A,

B.

Plate IX.

TABULAR VIEW OF CHARACTERISTIC COMPONENTS OF THE INTRUSIVES OF THE SNOWBANK LAKE AREA.

	Green diopside	Aegerite-augite	Microcline in individual crystals	Unstriated albite	Lens-like intergrowths	Excessive titanite	High soda	High in Apatite
Microcline-oligoclase syenite	X	X	X	X	X	X	X	X
Albite syenite	X	X		X	X	X	X	X
Quartz diorite	X			X	X	X	X	X
Granite	X			X	X	X	X	X
Granite porphyry dikes	X		X	X	X	X	X	X
Syenite dikes	X		X	X	X	X	X	X
Granitic dikes	X		X	X	X	X	X	X
Pegmatite dikes					X	X	X	X
Aplite dikes	X			X	X	X	X	X
Bostonite dikes	X			X	X	X	X	X
Malchite dikes	X			X	X	X	X	X
Lamprophyr dikes	X			X	X	X	X	X
Cacaquabic granite	X	X		X	X	X	X	X
Giants Range granite	X		X	X	X	X	X	X